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PENNSYLVANIA
GEOLOGICAL SURVEY
FOURTH SERIES

Bulletin G 1

A Syllabus of

PENNSYLVANIA GEOLOGY *and* MINERAL RESOURCES

By
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DEPARTMENT OF INTERNAL AFFAIRS
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TOPOGRAPHIC AND GEOLOGIC SURVEY
GEORGE H. ASHLEY, *State Geologist*

HARRISBURG, PA.
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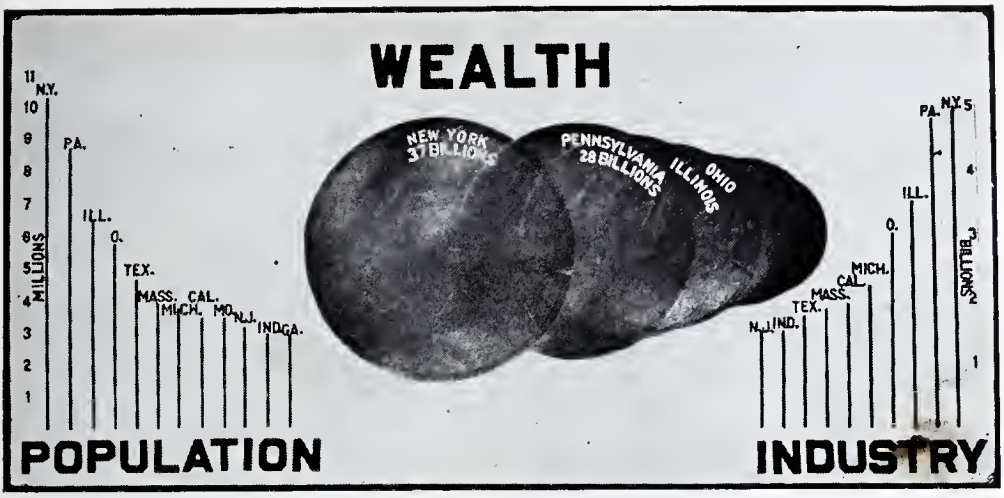
The scenery of Pennsylvania is the result of natural forces acting through hundreds of millions of years. Every feature of the landscape, each river bend, each ravine and hill, each level mountain top, each roll in the valley has a reason. It may be a difference in the hardness or pitch of the rock; it may be the glacial ice paused a moment at that point.
Susquehanna Valley at Lanesboro, Pa. Photo by D. S. Harding

PREFACE.

The Geologic Survey receives many requests for general information regarding the State's geology, geologic history, mineral resources, and geologic phenomena in general. This little bulletin has been prepared to answer these and other questions, and to give our citizens and junior citizens a bird's-eye view of the State's geologic history and mineral resources.

It takes the place of two bulletins of the preceding Survey: Report No. 9, Minerals of Pennsylvania by Brown and Ehrenfeld, and Report for 1906-1908, by the present writer and others, formerly used for answering such questions, but now out of print. It has been largely abstracted from two much more detailed reports now in preparation, one on The Rocks of Pennsylvania, the other on The Mineral Resources of Pennsylvania. The first of these was intended primarily to accompany the geologic map of the State, 40″ x 64″, to be printed in 1931 but its completion has been delayed in the hope of getting additional light on many unsettled stratigraphic problems. For that reason brief descriptive tables of the rock formations and a preliminary stratigraphic chart have been added to this bulletin. A large part of the text in the first part of the bulletin was published without illustrations in the *Pennsylvania School Journal* for 1927-1928 in 12 chapters. That material is here brought together and illustrated.

All photographs not otherwise credited were taken by the writer.



A SYLLABUS OF PENNSYLVANIA GEOLOGY AND MINERAL RESOURCES

By Geo. H. Ashley

PENNSYLVANIA.

Introduction. That Pennsylvania, though 32d in size among the States, is second in population, wealth, and productive industry is well known to all. That her important place in the sun is largely due to her great mining and metallurgical industries is also widely recognized, though not many realize how largely her mines are the roots of her present prosperity and power, and few know how largely this has been due not so much to Pennsylvania's possession of superior mineral resources as to the initiative and enterprise of her citizens.

The people of Pennsylvania even from Colonial times have recognized the importance of mining to the life of any state or nation, and have persistently carried on seientific research in the discovery and location of mineral resources and their vigorous development when found. The sciences, and geology in particular, have long had a prominent place in the minds of Pennsylvanians. The American Philosophical Society had its home in Pennsylvania and as early as 1786 began publishing papers on geology, including one in 1793 by Franklin on a theory of the earth, and in 1809 a geological map of the United States by Wm. McClure. In 1812, the Philadelphia Academy of Natural Sciences was established and in 1832 the Geological Society of Pennsylvania. Out of this interest came the First Geological Survey of Pennsylvania; and to this day Pennsylvanians have continued to study the geology and mineral resources of their State.

Geology of interest. Aside from giving a knowledge of the earth's mineral resources, geology has a keen interest for many people because it deals with facts that are very close to all of us. We live on the earth and most of us derive our living directly or indirectly from it. In these days of the automobile most of us travel more or less and see many things that excite our curiosity. Here is a narrow gap in the

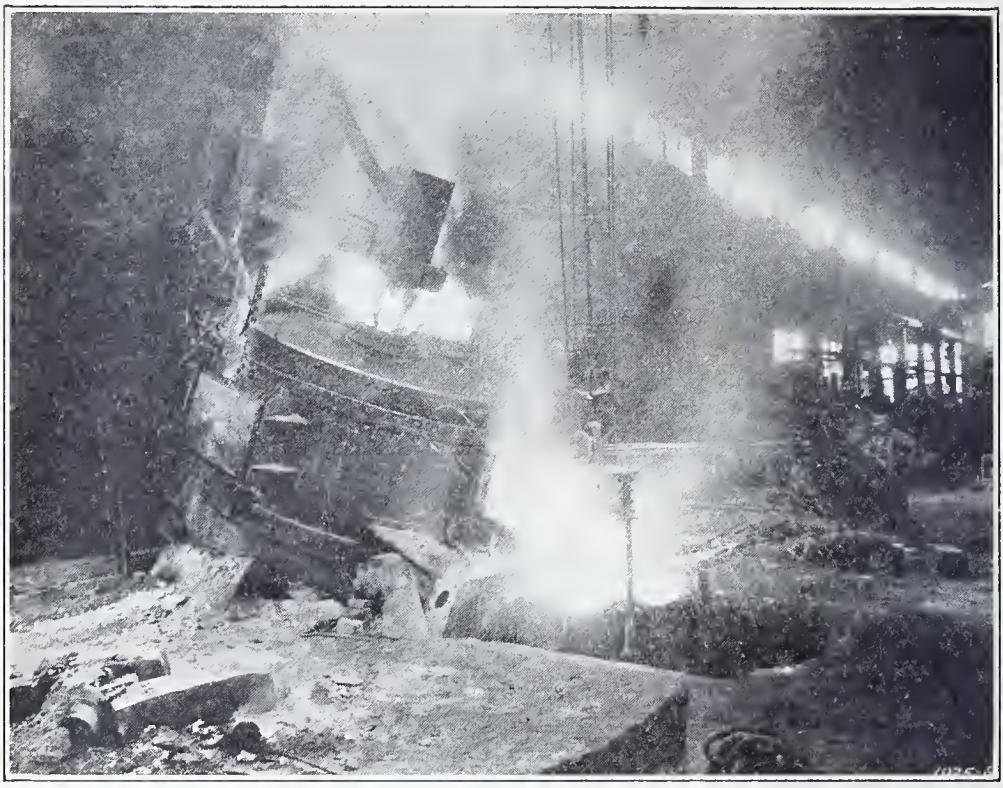


Fig. 1. Mining and metallurgy are the foundation of Pennsylvania's greatness. Together with industries based on metals they are responsible for two-thirds of all the industries of the State. Pouring steel from electric furnace. Photo by Altwater and Brother.

Fig. 2. Gaps of Susquehanna River through Kittatinny or First, and Second Mountains, north of Harrisburg. The origin of these gaps is explained beyond. Photo by George W. Stose.

mountain which looks as though the river had "broken" through it. In the river gap are beds of rock standing on edge; and many of these contain sea shells lying in bands parallel to the bedding. How did these beds come to be turned up on end? Driving over the Lincoln Highway one is apt to stop at the top of Tuscarora or Cove Mountain, and looking westward, observe the levelness of the mountain tops that form the horizon. Why are the crests of the ridges so even?

There is a reason for everything we see in nature. As suggested under the frontispiece, each bend of a river, the location of each stream, the location, size, and height of each hill, has been determined by definite conditions, such as hardness of rock, pitch or lay of beds, etc. This Syllabus can only suggest some of the larger phases of this matter.

Pennsylvania's debt to mining. To realize more fully Pennsylvania's debt to mining let us recall certain facts. Some figures given at the end of this chapter show that, of an estimated total return for industry for 1923 of $10,780,000,000, a total of $7,500,000,000 may be credited to mining, metallurgy, and the manufacture and transportation of mineral products. Of this over $2,500,000,000 are credited to mining and metallurgy. Or look at it in another way. Lackawanna, Luzerne and Schuylkill counties are in the anthracite field. Compare them with four adjoining counties, Columbia, Monroe, Pike and Wyoming, of about the same aggregate size (2,040 square miles against 2,120 square miles for the first three). The coal counties have a population of 895,051 (1920) compared with 93,563 for the others; and an industry valued at $601,397,000 (1926) compared with $49,133,900, a difference of about 12 to 1. Or compare Luzerne and Huntingdon counties, which are about the same size, 892 and 918 square miles. Population of Luzerne 391,001 or 438.8 per square mile, of Huntingdon 39,848 or 43.4 per square mile, or as 10 to 1. The value of all industries in Luzerne (1921) was $304,662,900, of Huntingdon County $9,549,000, or as 35 to 1. In these instances there is hardly a doubt that mining has been the basic cause of the difference. Multiply this over the State and it is easy to see why mining is so fundamental to Pennsylvania's industry and greatness.

Pennsylvania's place in mining. Pennsylvania is not only a great mining State, she is by far the greatest among the States and the peer of any state or nation in the world. Until recently the value of her mineral production has equaled or exceeded that of her three nearest competitors. For example, in 1918, the mineral production of Pennsylvania had a value of $979,000,000; of Oklahoma, West Virginia and Illinois together $936,000,000. In 1923, Pennsylvania produced minerals to the value of $1,226,284,404 out of a total for the country of $5,998,800,000 or 23.60 per cent. In 1927, her production was $936,693,474 in a total of $5,529,500,000 or 19.11 per cent of the total.

Compare her with other countries; as in 1923, when the value of minerals produced in Pennsylvania was $1,226,000,000, in Great Britain $1,158,000,000, in Germany less than $1,000,000,000, in France about $800,000,000. The ratio may have changed slightly since that time.

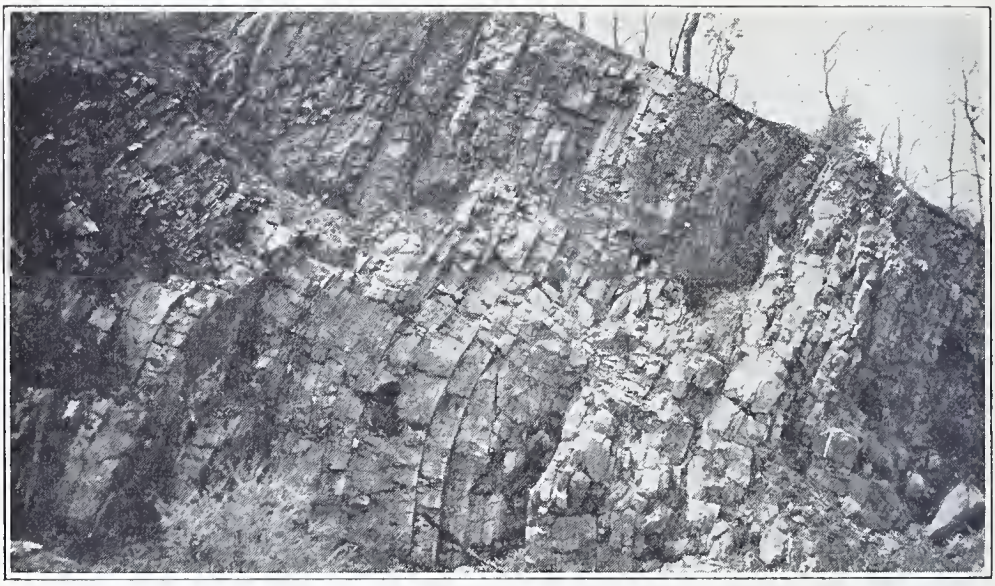


Fig. 3. Beds of limestone standing at a high angle. These were originally laid down in the sea in horizontal position. Beekmantown limestone of the Canadian system in a railroad cut near the mouth of Elk Run, east of Tyrone, Blair County.

Fig. 4. View west of Tuscarora Mountain on Lincoln Highway showing the level tops of the mountains. This is a characteristic of nearly all of Pennsylvania's mountains. These level tops were formerly parts of plateaus, and still longer ago were parts of great plains that covered all of the State. (See story beyond).

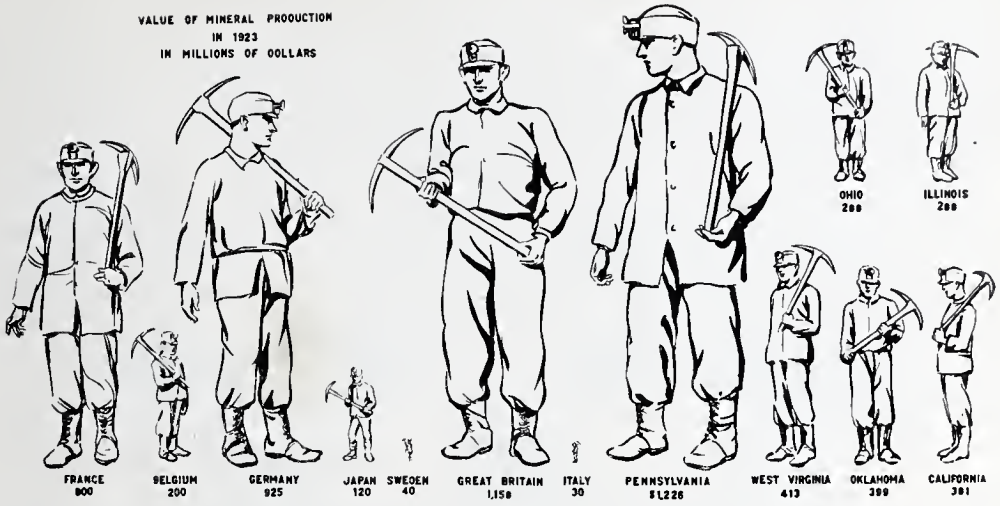


Fig. 5. Relative importance of mining in Pennsylvania and other States and countries.

Why does Pennsylvania lead? Pennsylvania's lead is due mainly to the initiative, enterprise and industry of her people. On the whole, Pennsylvania has no more and no better mineral resources than some other States. In coal resources, that is, coal in the ground, Pennsylvania comes far down the line, standing about ninth according to M. R. Campbell. Yet for years she produced more than one-half of all the coal mined in the United States. Other States far surpassed her

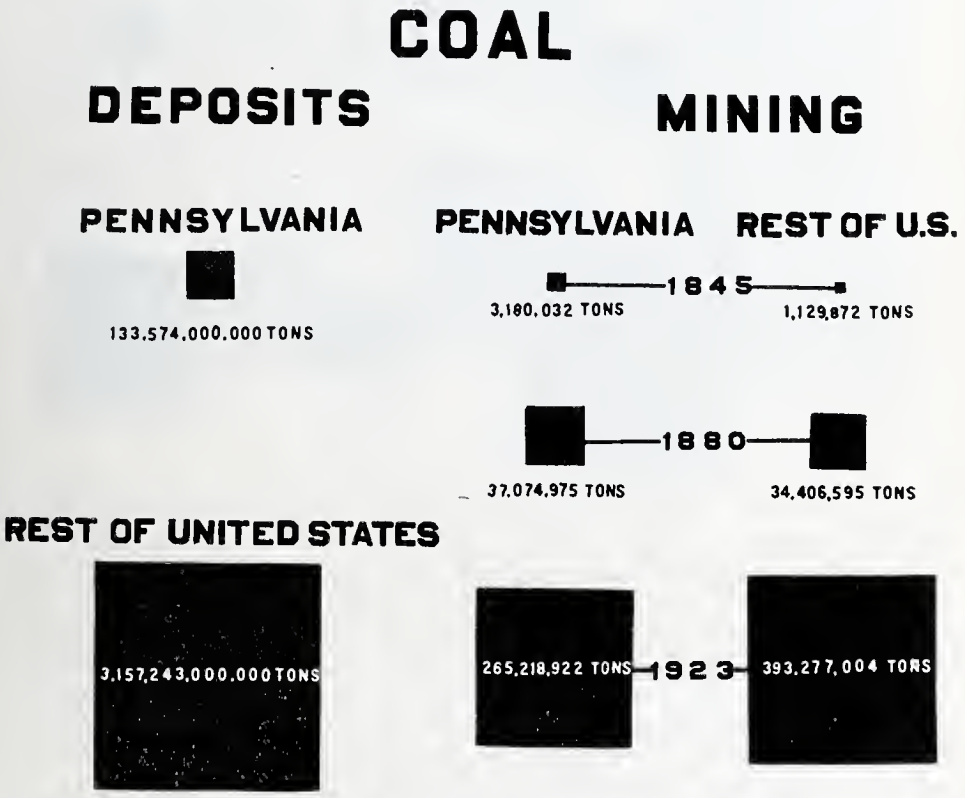


Fig. 6. Chart showing comparison of Pennsylvania and the rest of the United States in coal deposits and coal mining.

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in deposits of oil and gas. Yet Pennsylvania pioneered the oil and gas industry and for years stood almost alone as an oil and gas producer. Pennsylvania is estimated to have started with about 1/70th of the iron ore of the country, yet for years she produced about one-half of all the iron ore mined, and still produces about one-third of all the pig iron made in the country, and more than any other State or foreign power. Her supplies of limestone, sandstone, and clay are neither larger nor better than those of many of her sister States, yet she is a leader in their production.

In 1923 according to Federal statistics, Pennsylvania held first rank in 45 industries; 2d rank in 44 industries; 3d rank in 46 industries; 4th rank in 30 industries; and 5th rank in 37 industries, or 202 of 336 industries listed by the U. S. Census Bureau.

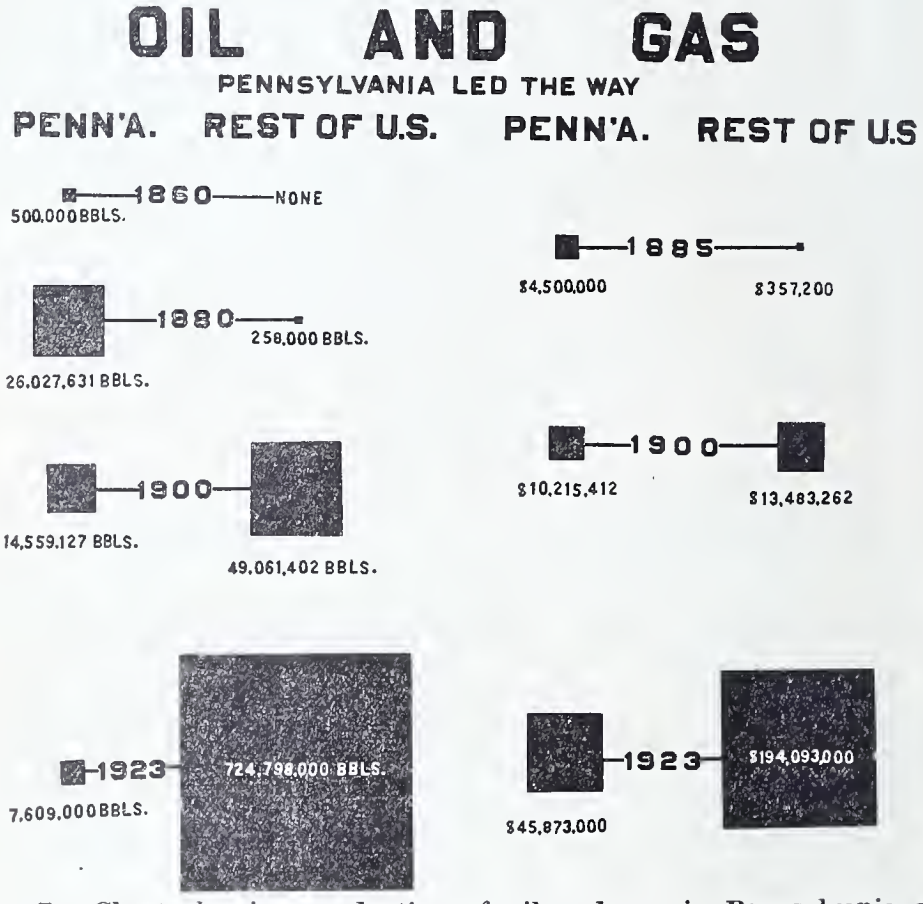


Fig. 7. Chart showing production of oil and gas in Pennsylvania and the rest of the United States.

From these figures it is evident that her leadership is not due to her possession of mineral resources lacking to others (except anthracite) but rather to the intelligence, initiative and energy of her people.

Pennsylvania levies on all the world. Having established great mining and metallurgical industries, Pennsylvania has not been content to use her own mineral products alone. She has remembered that a ton of unmined iron ore in the ground may be worth 15 cents, mined it may be worth $2.50 (1928). Convert two tons of ore into a ton of pig iron and it is worth $18.00 a ton, or converted into steel

watch springs, $280,000 a ton, or into hair springs for watches $300,000,000. Accordingly she has fed her furnaces with iron ore from Lake Superior, New York, Cuba, Sweden, and elsewhere. She smelts 16 per cent of the zinc of the United States though she does not mine any. There is hardly a country in the world from which Pennsylvania does not draw raw material, even Greenland and Africa contributing their minerals.

Of course Pennsylvanians should not claim all of the credit for all this greatness, for this State has a climate second to none in its effect on industry and culture, and she undeniably has a strategic

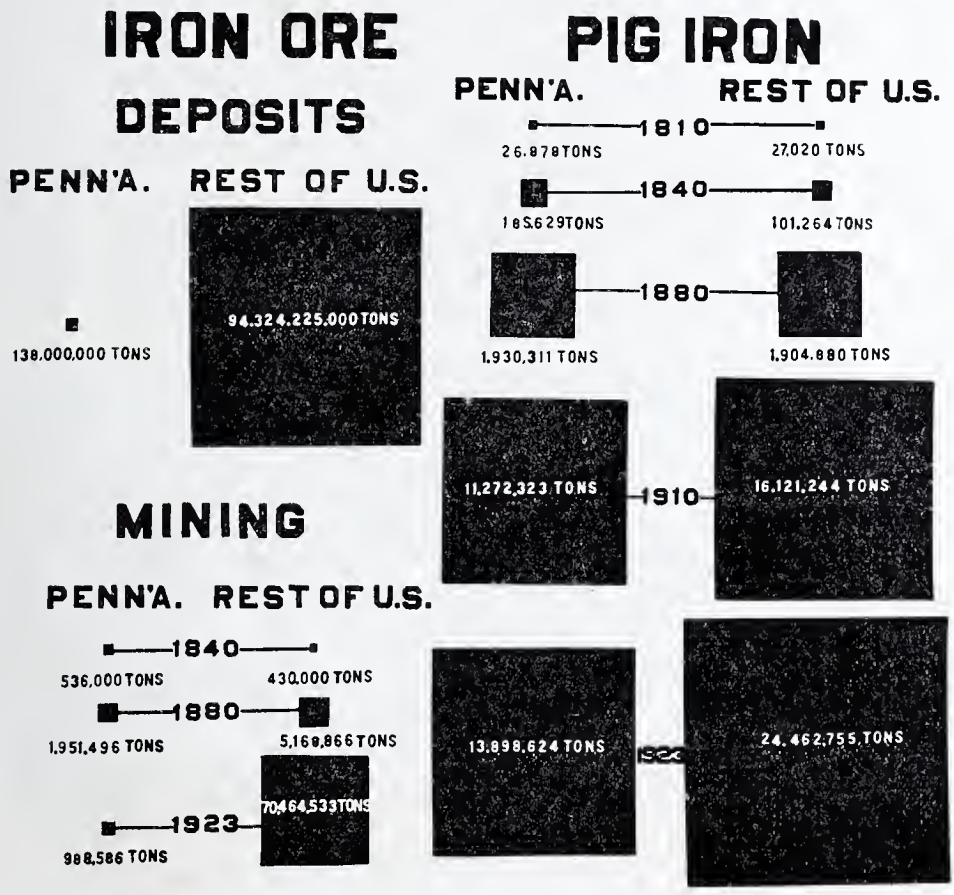


Fig. 8. Chart showing Pennsylvania's place in the iron industry of the United States.

position with reference to the seaboard and the early centers of population. Few people realize that New York City lies just about east of Easton and farther south than Wilkes-Barre and Sunbury; that Philadelphia, Pennsylvania, is only about one-half as far from New York harbor as Albany, New York. The Pittsburgh coal field is not much nearer the Atlantic coast than the Pocohontas coal field, and the coal is no thicker or better, but Pittsburgh was actively mining coal 170 years ago and building canals to market it, while Pocohontas coal was first mined less than 50 years ago.

Geology and mining. Geology and mining have always gone hand in hand. While in the early days much mining started without the

aid of geology, today mining leans heavily on geology. Some people think geology's only service to mining is to find minerals. It is true that the geologist is often the first to find new mineral deposits or to recognize the value of chance finds by others, but today the major service of geology is in guiding development, in warning against unprofitable undertakings, in evaluating mineral deposits or mineral lands. Where the geologist has made detailed surveys he can usually tell very closely what mineral deposits underlie any acre of land, the depth to those deposits, their relative value, how they lie, possibly what difficulties are likely to be encountered in their exploitation. How this is done will be explained farther on. The actual mining of the deposits is the province of the mining engineer, but more and more the economic geologist, though not actually supervising the mining of minerals, must understand the economic as well as the physical factors that affect the value or use of any mineral deposit. A mineral deposit may be of very high grade and yet have no present value because the market demand is all being met by other deposits which have the advantage of lower freight rates, better mining conditions, or of long established trade. The first question asked regarding any mineral deposit of good quality is "Is there any unsatisfied market demand for this material, or does it have any inherent advantages over similar materials elsewhere?"

Geology is useful to mining because minerals do not occur at random, but under certain definite conditions. Thousands of geologists studying mineral deposits all over the world have brought together a mass of data from which it has been possible to describe the conditions under which any mineral occurs. Thus, in order that there may be a supply of oil, there must have been a source of oil, a reservoir of porous rock, enough heating, but not too much, to have distilled the oil out of its source, folding to localize the accumulation, etc. Only a narrow belt in western Pennsylvania fulfills all of these conditions, and only there should oil be looked for. The same thing is true of coal, gold, iron and other minerals, rocks and ores. Geologists do not know all about any of these subjects, and in many instances not all of the factors can be judged from the surface. To be well informed the geologist must know the conditions under which any mineral occurs anywhere in the world.

Some General Facts About Pennsylvania.

Area in square miles: Land 44,832, water 294; total 45,126.
Population (1930) 9,631,350.
Wealth, (1922) $28,833,745,000; (1926) estimated $33,876,861,000.

Taxes paid in Pennsylvania:

State taxes, 1930 ..... about	$161,414,000
Federal income tax, 1930	215,330,000
Federal misc. internal revenue taxes, 1930	16,330,000
Federal import duties, 1930	43,438,000
Federal miscellaneous receipts, 1924 (prorated) ..	50,000,000
Total State and Federal taxes	$486,512,000
Local taxes, estimated	250,000,000
Total cost of government in Pennsylvania	$736,512,000

A Picture of Pennsylvania's productive industries:

Based on Forests		$591,234,000
Forestry	$13,000,000	
Secondary industries	515,234,000	
Freight	63,000,000	
Based on Farms		$2,693,114,000
Farm products	$505,756,000	
Manufacturing from these	2,054,358,000	
Freight	133,000,000	
Based on Minerals		$7,498,857,000
Mining (1923)	$1,141,241,000	
Metallurgy	1,123,919,000	
Manufactured from minerals	4,205,697,000	
Freight	1,028,000,000	
Grand total		$10,783,205,000

THE ROCKS OF PENNSYLVANIA, AND THE STORY THEY TELL.

It is well recognized that coal, iron, and other mineral resources of any country are the result of processes and accumulations similar to those going on today. They have not always been where and as we find them. Likewise the earth's surface as a whole is constantly changing; there are no "eternal hills." Every rain lowers the hills, however slightly, and to that extent fills up the ocean. In time the hills will disappear. Other forces however, are acting to raise the mountains. Earthquakes and volcanoes are mere incidents in the action of these titanic forces. Most of the seacoasts of the world show evidence of recent rising or sinking. The present surface of the earth is the result of a long history of mountain building and sea deepening, of land reduction and sea filling, of sea encroachments and retreats so vast that geologists believe these events must have required hundreds of millions of years.

The debris of the land carried to and laid down on the sea bottom eventually became layers of hard strata in the earth's crust.

As the reports of the Geologic Survey contain many geologic terms, many of which may be unfamiliar to the general reader, some of these most frequently used are defined and illustrated in the following pages.

The Kinds of Rock in Pennsylvania and Their Origin.

There are three principal kinds of rocks: 1. Bedded or sedimentary rocks: sandstones, shales and limestones; 2. Igneous rocks: granite and trap; 3. Metamorphic rocks: marble, slate, schists.

Sedimentary Rocks. These rocks occur as beds from a few inches to a thousand feet thick and cover from a fraction of an acre to thousands of square miles. Most of them were laid down in the sea as beds of sand, mud or limy material, or in lakes, lagoons, river bottoms or coastal swamps. The material was originally derived from the disintegration or solution of igneous rocks, from the remains or products of animals or plants, or from chemical action. In general they were

deposited over a slowly sinking sea bottom. At first these deposits were loose sand or mud. As they were buried beneath other layers the increasing weight and pressure condensed them into rock, 100 feet of mud making only 60 feet of shale. Limestone, shale and sandstone were made in this way.

Clean sand makes pure sandstone. Commonly mud or other substance was mixed with the sand, resulting in a muddy or shaly sandstone, a limy sandstone, or a ferruginous sandstone (ferruginous meaning iron-bearing, from *ferrum,* the Latin word for iron). So likewise we have sandy shales, sandy limestones, limy shales, and shaly limestones. In sandstone the sand grains are cemented by iron, silica, or lime. Gravel hardens into conglomerate or pudding-stone. The color of the rock is usually determined by the presence of iron, carbon or other substance in it.

Sedimentary rocks include beds of salt laid down in lagoons where sea water has evaporated, beds of coal where vegetal matter growing in swamps has been buried and preserved, beds of clay, of iron ore, of chert, and of some other materials.

Igneous Rocks. Igneous rocks are formed by solidification from a molten state. Rock material deep in the crust of the earth where the temperature is high would be melted or dissolved and soft like melted iron or tar were it not for the high pressure. When the pressure is released by the opening of a crack in the crust or otherwise the hot rock will flow, following up crevices or squeezing between beds, sometimes reaching the surface and spreading out as lava or forming a

Fig. 9. A dike of igneous rock intruded along a crevice in sedimentary beds. Cornwall, Lebanon Co.

volcano. Lava may be very porous or dense and glassy. Igneous rocks which cool at or near the surface solidify in minute crystals, like the trap in southeastern Pennsylvania. If, however, the rock cools slowly at a great depth large crystals are produced that can be plainly seen by the naked eye, as in granite.

Igneous rocks are therefore divided into classes according as the grain is coarse, fine, or like glass, and according to the minerals into which they crystallize on cooling. Granite, syenite, diorite, gabbro, basalt and many others occur in Pennsylvania.

Metamorphic Rocks. These rocks are altered sedimentary and igneous rocks. Intense earth pressures with a rise in temperature may not melt the rocks but may produce other changes, both chemical and structural, as changing shale to slate and limestone to marble. The pressure which crushes or folds the rock may change the position of the

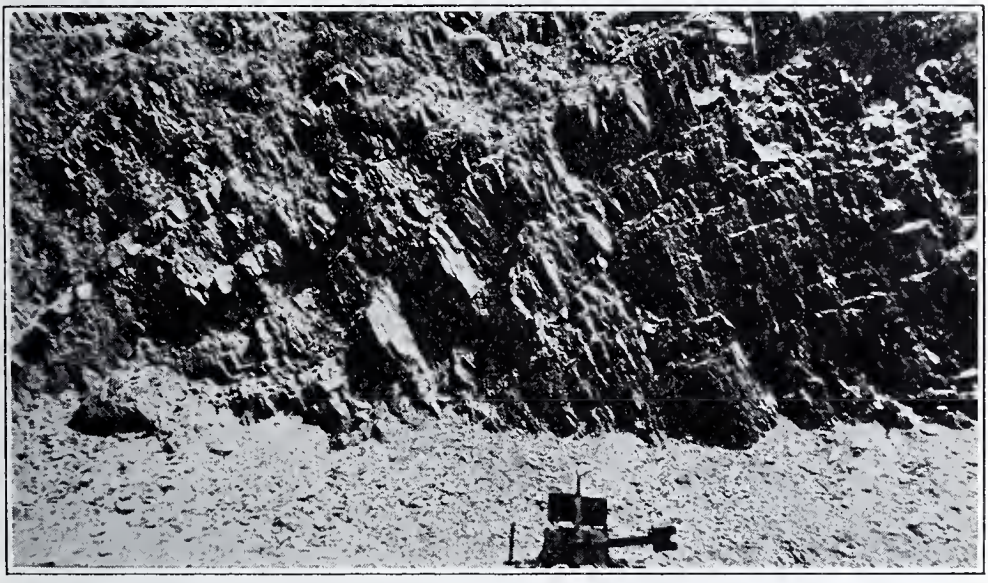


Fig. 10. Sedimentary rock metamorphosed by squeezing so that it breaks in splinters or plates across the bedding. Lehigh Gap, Lehigh Co.

original flakes or grains so that the rock splits across the bedding or in thin plates or slivers. Such pressures may affect igneous rocks as well as bedded rocks, squeezing granites into gneisses and other rocks into schists. Rocks are metamorphosed also by the intrusion of igneous rock, the heat of which, together with a transfer of material, alters the rock with which the molten rock comes in contact.

Rock Thickness and Conditions of Deposition.

If, after being laid down in the sea, the rocks had stayed there we should know nothing about them. The rocks we know have been lifted above sea level. Had they been lifted straight up we would still know only the rocks at the top except as we sank wells or mine shafts into them or they are exposed in valleys. But uplifting usually tilts the rocks, or great horizontal pressure has folded them as a pile of rugs is folded when you push against the edge. The rocks of Pennsylvania

have been folded thus. Some of the folds originally were several miles high. Later rain and running water wore down the tops of the folds, exposing the edges of the rocks.

Thickness. The Pennsylvania Railroad from Gallitzin to Altoona and from Tyrone to Huntingdon cuts across 27,000 feet of bedded rocks, standing like a lot of books set on edge on a table. East of Kittatinny Mountain and in the South Mountains still older rocks increase the total to over 40,000 feet; and in southeastern Pennsylvania are 10,000 feet of still older beds and 29,000 feet of younger beds, as described later.

Slight folding in southwestern Pennsylvania exposes 3,000 feet of rocks and deep drilling reveals 7,700 feet more; drilling in north-

Fig. 11. Measuring the edges of sedimentary rocks exposed along the railroad at Horseshoe Curve, Blair County. The edges of 13,000 feet of rock may be measured and examined between Gallitzin and Altoona.

western Pennsylvania reveals still more. The geologist recognizes in these exposures and drillings the same rocks that are upturned and exposed east of Allegheny Mountain. Our information shows that the rocks get thinner and finer-grained toward the northwest, sandstones grade into shales, and shales into limestones.

So we conclude that while most of its rocks were being laid down, Pennsylvania was part of an inland sea with land at the east extending far out into what is now Atlantic Ocean and that rivers flowing westward from this land deposited in this Appalachian sea the sands, muds and limy material that today form our sandstones, shales and limestones.

Laid down in shallow water. Our sandstones show abundant ripple marks on the bedding such as wind and waves make in shallow water on the seashore today, indicating that the rocks of Pennsylvania were

laid down not in a deep sea but layer after layer on a shallow, slowly-sinking sea bottom. So too, the character of our rocks indicates that the land supplying this material was slowly rising, sometimes high but commonly low, probably rising, seesaw fashion, as the sea bottom under Pennsylvania sank.

Proportions of the sedimentary rocks. About 30 per cent of the sedimentary rocks of Pennsylvania are sandstone, 43 per cent are shale, and 27 per cent are limestone. Coal, salt, etc. make up less than 1 per cent. While sandstones, shales and limestones occur all through the column of rocks, limestones predominate in the lower part and shales in the upper and middle parts. A thousand feet or more of one kind of rock may occur in one part of the column but commonly sandstones, shales and limestones from a few feet to several hundred feet thick alternate irregularly.

Total volume of rocks. If the highly folded and crushed rocks of central and eastern Pennsylvania were spread out flat as originally laid down and western Pennsylvania stood fast, the Philadelphia region would be shoved across New Jersey and possibly out into Atlantic Ocean. Combining this original area with the thickness of the several rocks in different parts of the State, we estimate that the main body of bedded rocks of Pennsylvania originally occupied a volume of more than 250,000 cubic miles, an average thickness of about 25,000 feet for the whole State. This does not include the 10,000 feet of very old rocks or the 29,000 feet of younger rocks in southeastern Pennsylvania.

What Rocks Are Made Of.

Rocks consist of one or more minerals. Minerals are naturally occurring inorganic substance having a characteristic chemical composition. They consist of a definite and invariable number of elements in combination. The elements are substances like oxygen, hydrogen, carbon, and iron that normally cannot be broken up into different parts. There are 92 elements, but two of these, oxygen (O), and silicon (Si) make up three-fourths of the earth's crust. These and six others constitute over 95 per cent of the rocks. The commonest rock-making elements are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), magnesium (Mg.), potassium (K), titanium (Ti), hydrogen (H), phosphorus (P), carbon (C), manganese (Mn), and chlorine (Cl).

These elements combine to make hundreds of minerals, but the bulk of the rocks contain only a few of these. Silica or quartz (SiO_2) makes up nearly 60 per cent of the earth's crust. Alumina (Al_2O_3) which occurs in clay or mud makes up 15¼ per cent. Lime (CaO) makes up 5 per cent. Silica (SiO_2) occurs alone as quartz, and in a great number of combinations in minerals called silicates, such as feldspar, mica, and garnet. The following table gives a very few of the commonest rock-forming minerals with their composition, color, luster, hardness (H) on a scale of 10, crystal system, cleavage (C), or fracture (F), specific gravity (G), and common habit.

COMMON ROCK-FORMING MINERALS

Name	Composition	Color	Luster	H.	Crystal system	Cleavage, fracture	G.	Common habit
Quartz	SiO_2	White or colored	Glassy	7.	Hex.	C none F conchoidal	2.6	Hexagonal pyramids and prisms or massive
Feldspar:								
Orthoclase	$KAlSi_3O_8$	Flesh—brown	Glassy-pearly	6. 6.5	Mono.	C good basal	2.6	Crystals, cleavage pieces massive
Albite	$NaAlSi_3O_8$	White—gray	Glassy	6. 6.5	Trie.	C fair—basal	2.6	Small crystals and platy masses
Anorthite, etc.	$CaAl_2Si_2O_8$	White—gray	Glassy	6. 6.5	Trie.	C good—basal	2.7	Crystals
Hornblende	Silicates of Ca, Mg, Fe, & Al.	Greenish or brownish—black	Glassy-silky	5. 6.	Mono.	C prismatic good	2.9 3.4	Massive, fibrous, long prisms
Pyroxenes (Augite)	Silicates of Ca, Mg, Fe, & Al.	Greenish or brownish—black	Glassy	5. 6.	Mono.	C prismatic, fair	3.3	Almost square prisms, massive
Micas		Brownish—gray	Pearly-glassy	2. 2.5	Mono.	C basal—perfect	2.7 3.—	Micaceous in flakes or in sheets
Muscovite	$H_2KAl_3(SiO_4)_3$							
Lepidolite	$(LiK)_2Al_2(F,OH)_2Si_3O_9$	Pale pink lavendar	Pearly	2.5 4.	Mono.	"	2.9	Sealy masses, flakes
Biotite	$(HK)_2(Mg.Fe)_2(Al,Fe)_2(SiO_4)_3$	Black, brown, green	Glassy	2.5	Mono.	"	2.7 3.1	Scales, flakes, sheets
Garnet many kinds	Silicates of Ca, Al, Fe, & Mg.	Deep red and others	Glassy	6.5 7.5	Isom.	F. uneven	4.3	Crystals, grains, massive
Tourmaline	Borosilicate of Al.Li.Fe,OH,etc.	Black, green, pink, red	Glassy	7. 7.5	Hex.	C none F uneven	3. 3.2	Prisms, often radiating
Olivine	$(Mg.Fe)_2SiO_4$	Green—brownish green	Glassy	6.5 7.	Orth.	C poor brittle	3.3	Grains, rounded masses
Epidote	$Ca_2(Al,Fe)_2(Al\text{-}OH)(SiO_4)_3$	Pistachio green	Glassy	6. 7.	Mono.	C basal, perfect brittle	3.2 3.5	Crystals, long prisms, massive
Talc	$H_2Mg_3(SiO_3)_4$	White to pale green	Pearly greasy—dull	1. 1.5	Mono.	C basal, perfect	2.8	Foliated, compact, massive, fibrous
Serpentine	$H_4Mg_3Si_2O_9$	Green	Greasy-silky	2.5 4.	Mono.	F conchoidal or splintery	2.6	Massive, fibrous as in asbestos
Chlorite	$H_8(Mg,Fe)_5Al_2Si_3O_{18}$	Green	Pearly-glassy	1.5 2.5	Mono.	C basal, perfect, tough	2.8	Foliated, micaceous, sealy, flaky
Calcite	$CaCO_3$	White or colored	Glassy	3.	Hex.	C pronouneed brittle	2.7	Rhombohedrons, granular, massive
Dolomite	$(CaMg)(CO_3)_2$	White, pink, gray	Glassy	3.5 4.	Hex.	C not prominent	2.9	Massive, harder than calcite
Pyrite (fool's gold)	FeS_2	Pale brass yellow	Metallic	6. 6.5	Isom.	C indistinct brittle	5.—	Cubes, octahedrons, granular, massive
Magnetite (magnetic iron)	Fe_3O_4	Iron black	Metallic	5.5 6.5	Isom.	C indistinct brittle	5.2	Octahedrons, sand, massive, granular
Hematite (red iron ore)	Fe_2O_3	Brownish red, cherry red, steel gray	Earthy, dull metallic	1 4		C none—earthy	5.	Massive, earthy masses, botryoidal, oolitic, powder splintery
Limonite (brown iron ore)	$2Fe_2O_3 3H_2O$	Yellow and brown	Earthy, dull submetallic	5 5.5		C none, uneven brittle	3.6	Compact, massive, stalactitic, botryoidal
Siderite	$FeCO_3$	Brown	Vitreous	3.5 4.5	Hex.	C perfect, brittle	3.8	Rhombohedrons, cleavage masses, balls
Chromite	$FeCr_2O_4$	Black	Submetallic pitchlike	5.5	Isom.	C none F uneven, brittle	4.3 4.5	Massive
Manganite	$MnO.OH$	Iron black	Metallic	4.	Orth.	C prominent. brittle	4.4	Prisms, columnar, in bunches
Psilomelane	MnO_2, H_2O, BaO, etc.	Dull black	Submetallic dull	5 6		C none, tough to brittle	3.7	Massive, botryoidal

SEDIMENTARY ROCKS: (laid down in beds on land or in water—mud, clay, sand, etc.)

Sandstone, consolidated fairly pure sand (aver. 78% SiO_2).
Shaly sandstone when mixed with clay matter.
Limy (or calcareous) sandstone when mixed with calcareous material.
Grit, sandstone containing small pebbles.
Conglomerate, consolidated gravel.
Ferruginous sandstone when deeply stained or impregnated with iron.
Quartzite, quartz sand cemented with quartz.

Shale, a mud rock splitting freely along the bedding.
Sandy shale, a freely splitting rock composed of fine-grained sand, or mud rock with sand grains.
Limy (or calcareous) shale, one high in limy material.
Mudstone, a rock high in alumina that does not split freely.

Limestone, a rock dominantly $CaCO_3$.
Shaly or sandy limestone when mixed with clay or sand.

Dolomite, a limestone containing 35 per cent or more $MgCO_3$.
Dolomitic limestone, limestone containing more than 10 or 15%, but less than 35% $MgCO_3$.

Clay, a structureless mud rock, either soft and plastic, or becoming so on wetting.

Flint clay, a hard, flint-like clay rock, used for fire brick.

Chert, a crypto-crystalline form of silica.

Coal, some iron ores, etc.

IGNEOUS ROCKS: (produced by cooling from a molten condition).

A. Composed of visible grain or crystals (cooled at great depth).
Even grained.
Granite—feldspar, quartz and mica.
Syenite—orthoclase and hornblende.
Diorite—plagioclase and hornblende.
Peridotite—olivine and pyroxene (without feldspar).
Gabbro—plagioclase and pyroxene.
Diabase—plagioclase and augite.
Porphyritic, large crystals in a matrix of small crystals.
Granite, syenite, and diorite porphyries, pegmatite.

B. Dense—grains or crystals not visible.
Nonporphyritic.
Felsite, light colored, usually feldspar, quartz and glass.
Basalt, dark colored, usually ferromagnesian.
Porphyritic.
Rhyolite-porphyry.
Basalt-porphyry.

C. Glassy igneous rocks (extruded to surface).
Obsidian, pitchstone, pumice, scoria, etc.

D. Fragmental igneous material.
Tuff and breccia (volcanic ash, bombs, etc).

METAMMORPHIC ROCKS: (derived from other rocks by heat and pressure).

Sediments	*Compacted rock*	*Metamorphosed rocks*
Gravel	Conglomerate	Gneiss or schists
Sand	Sandstone	Quartzite and schists
Silt and clay	Shale	Slate and schists
Lime deposits	Limestone	Marble

Igneous rocks	*Metamorphosed rocks*
Granites or syenites	Gneiss
Felsites, tuff, etc.	Slate and schists
Diorite, peridotite, gabbro, diabase	Hornblende schists and serpentine

THE ROCK BEDS, OR STRATIGRAPHY.

Rock Structures.

Rock beds. Most of the rocks underlying Pennsylvania are sedimentary rocks occurring in beds from a few inches or less, to 50 feet or more thick. A "formation" is a bed of rock or assemblage of beds which are considered together for purposes of description or mapping. A formation may be a few inches or 10,000 feet thick. (See Fig. 3).

In general rock beds have a very great lateral extent as compared with their thickness. A bed a few feet thick may be traceable over 10,000 square miles. Thus, it is thought that the Lower Kittanning coal bed has been traced from north central Pennsylvania to eastern Kentucky. The Pittsburgh coal bed is known to underlie almost 6,000 square miles, and has been carried away from an even larger area, and other coal beds and other rock layers are known to underlie still greater areas. The Loyalhanna limestone (Fig. 45) of western Pennsylvania is thought to have been originally continuous to Missouri and Iowa, though changing somewhat in character.

Overlap. In many geologic sections, it is found that a group of beds feathers out in a given direction, so that an overlying bed instead of resting only on the highest bed of the group below, lies successively on the edges of the several beds forming the group. These beds of the group may feather out because laid down against a rising land surface, or they have all been laid down regularly, and then the whole group arched up, and the top of the arch worn off. Later the truncated group of beds sank, and a new bed was laid down on the leveled surface. (See Fig. 12) This is called overlap.

Unconformity. If in the preceeding case, the group of beds was arched up so high that when eroded the beds were not horizontal, then a later bed laid on top of the group would make a visible angle to the

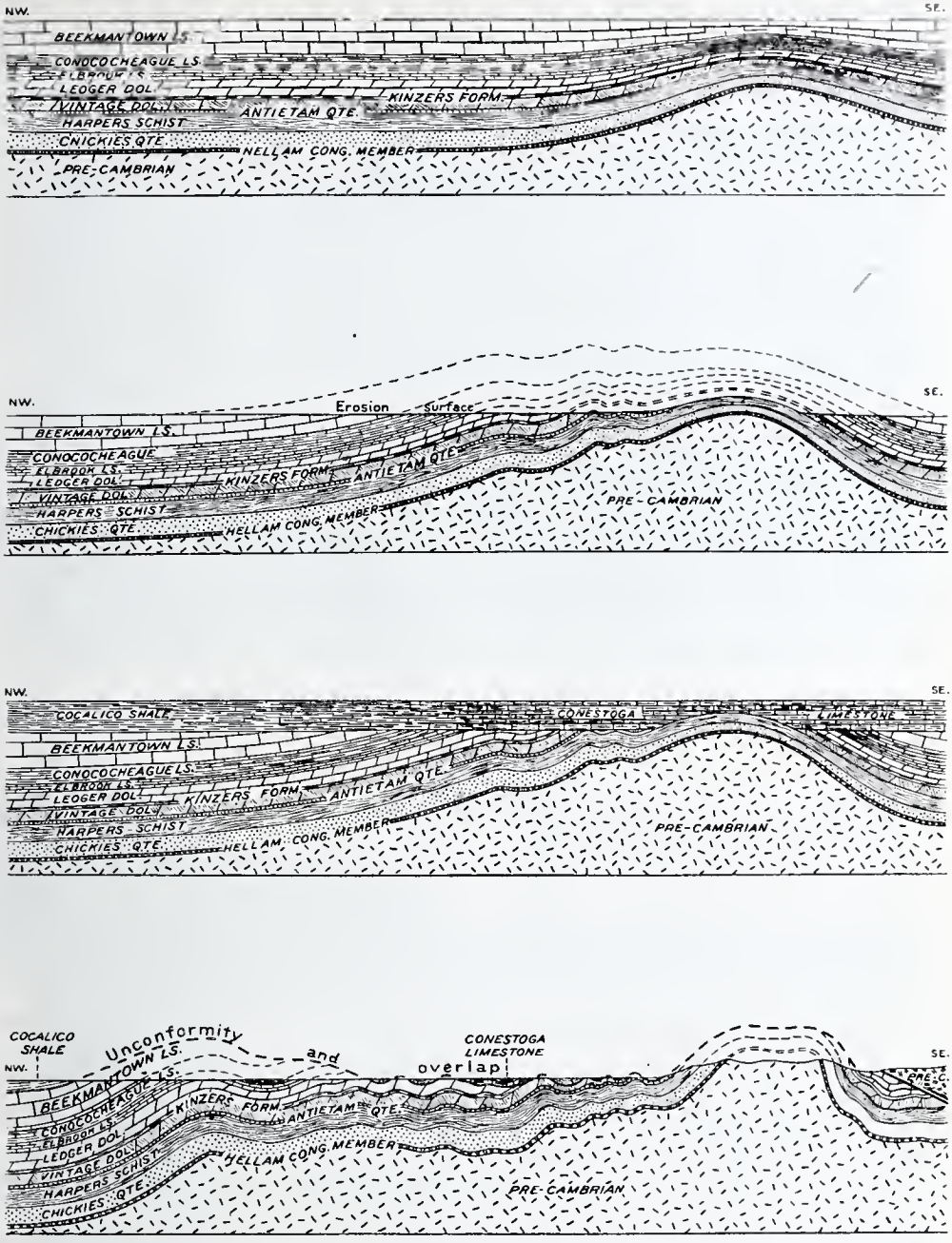


Fig. 12. Sketches illustrating overlap, unconformity and disconformity, from Mine Ridge, Lancaster County. In the first sketch the rocks are shown as laid down over a rising hump of Pre-Cambrian rocks. In the second figure the rocks have been lifted above sea level and worn down nearly to a plain. In the third figure this plain has sunk below sea level and mud and limy material washed in over the edges of the older rocks. Such a relation is called an overlap. Where the underlying beds meet the overlying beds at an angle the contact is an uncomformity. Where as in the center of the uplift the beds lie parallel, the contact is called a disconformity.

The lower figure shows conditions today after all of the beds have been folded and later the tops of the folds worn off. In addition at the right is shown a fault or break that has allowed some of the older rocks to be pushed up over the younger. After Geo. W. Stose.

beds of the group below. Such a contact is called an "angular unconformity." If the overlapping bed does not make a visible angle with the bedding of the underlying group, but rests on an irregular erosion surface, so that the plane between the two is not parallel to the bedding, this is called a disconformity.

Rock folds. The rocks of Pennsylvania as observed in stream banks, railroad and road cuts, seldom appear to lie horizontally, but are standing at more or less of an angle with plane of the horizon. This angle is called the angle of "dip." A horizontal line at right angles to the direction of dip is called the "strike." The direction of strike is the direction of a line of contact of the bedding plane with a horizontal plane.

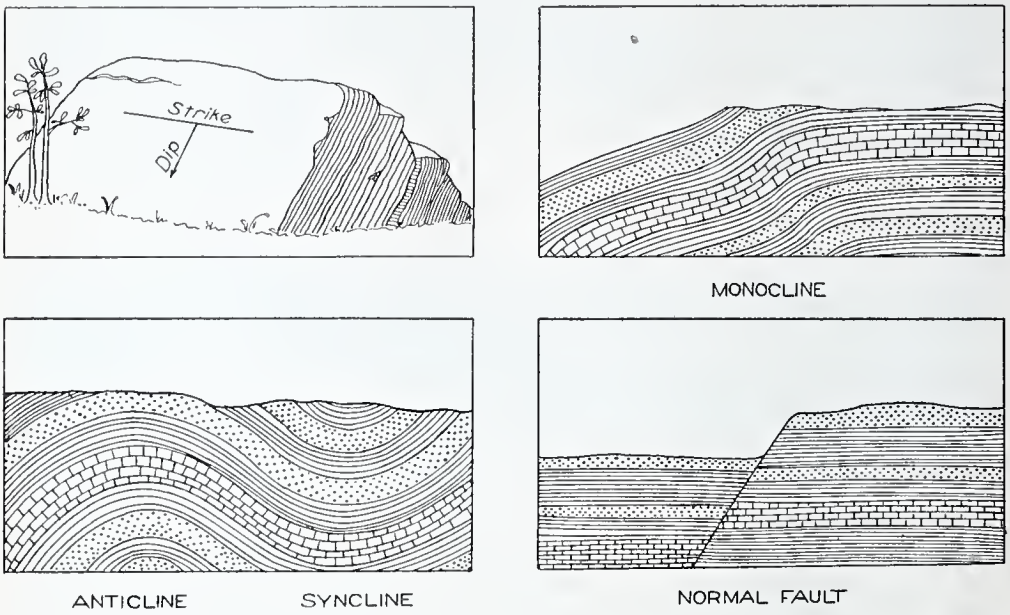


Fig. 13. Sketches illustrating dip and strike, monocline, anticline, syncline and a normal fault.

Followed along the "outcrop" or contact of a bed with the surface, a group of beds may continue to dip in the same direction for some distance. If followed far enough, however, the beds will usually change dip, forming a fold. An arch fold is called an "anticline" (Figs. 13 and 14). A basin is called a "syncline." An anticline or syncline may be "symmetrical" if the strata either side dip equally from a vertical plane through the center of the fold. If the dip either side is not the same, the fold is "asymmetrical." A line along the crest of the fold in a horizontal plane is the "axis" of the fold. If an anticline, or syncline, is pushed over so that one side overlies the other side, it is called "overturned" anticline or syncline. A geanticline or geosyncline is a wide fold, perhaps 100 miles wide.

Rock faults. As a result of strain in the rocks, they may break and the rocks on one side of the break move with relation to those on the other side. This is called a "fault." If the break and movement seem to imply a pulling apart of the beds, it is called a normal or

Fig. 14. An anticline, Juniata River near Amity Hall, Perry County.

Fig. 15. A syncline or down fold, Blue Mountain quarry, west of Slatington, Lehigh County.

gravity fault. (Fig. 13) If conditions imply a pushing together of the beds, it is called a "thrust fault," or "compression fault." Figure 17 illustrates how a thrust fault develops. On the Juniata River, near Birmingham, a fold has broken and been overthurst, until the strata below the plane of movement have been overridden by strata which belonged over 4,000 feet lower in the column of rocks. (Fig. 18)

Fig. 16. In the folding of the strata, the beds often break under the strain, so that at the line of break or fault plane the beds on one side meet those on the other side at a high angle. Fault on Elk Creek, near Tyrone, Blair County.

Minor rock structures. Rocks often show a series of breakage planes at right angles to the bedding. These are called "joints." Commonly there are two sets of joints, one much better developed than the other. Joints are of great aid in mining coal, in quarrying, tunnelling, and in other rock work. In gently folded strata jointing appears to be the result of stretching the beds. In highly folded beds, the pressure may have turned the particles of the rocks edgewise, so that the rock splits readily across the bedding, and at right angles to the direction of pressure. This readiness to split across the bedding is called "slaty cleavage." (Fig. 10).

Igneous rock forms. Igneous rocks may have flow structure and joints, but no true bedding. When igneous rock is forced up through the consolidated crust of the earth it may flow along between sedimentary beds and form a nearly horizontal, tabular mass. This is called a "sill." The Palisades of the Hudson are the exposed edge of a sill. An injection of igneous rock in a narrow crevice cutting across the bedding of sedimentary rocks or making a narrow band in igneous rocks is called a "dike." Many dikes occur in southeastern Pennsylvania and range in length from a few feet to several miles and in width from a few inches to hundreds of feet. Large irregular areas of igneous rock may be flows, sills or deep-seated bodies from which the cover has been removed by erosion.

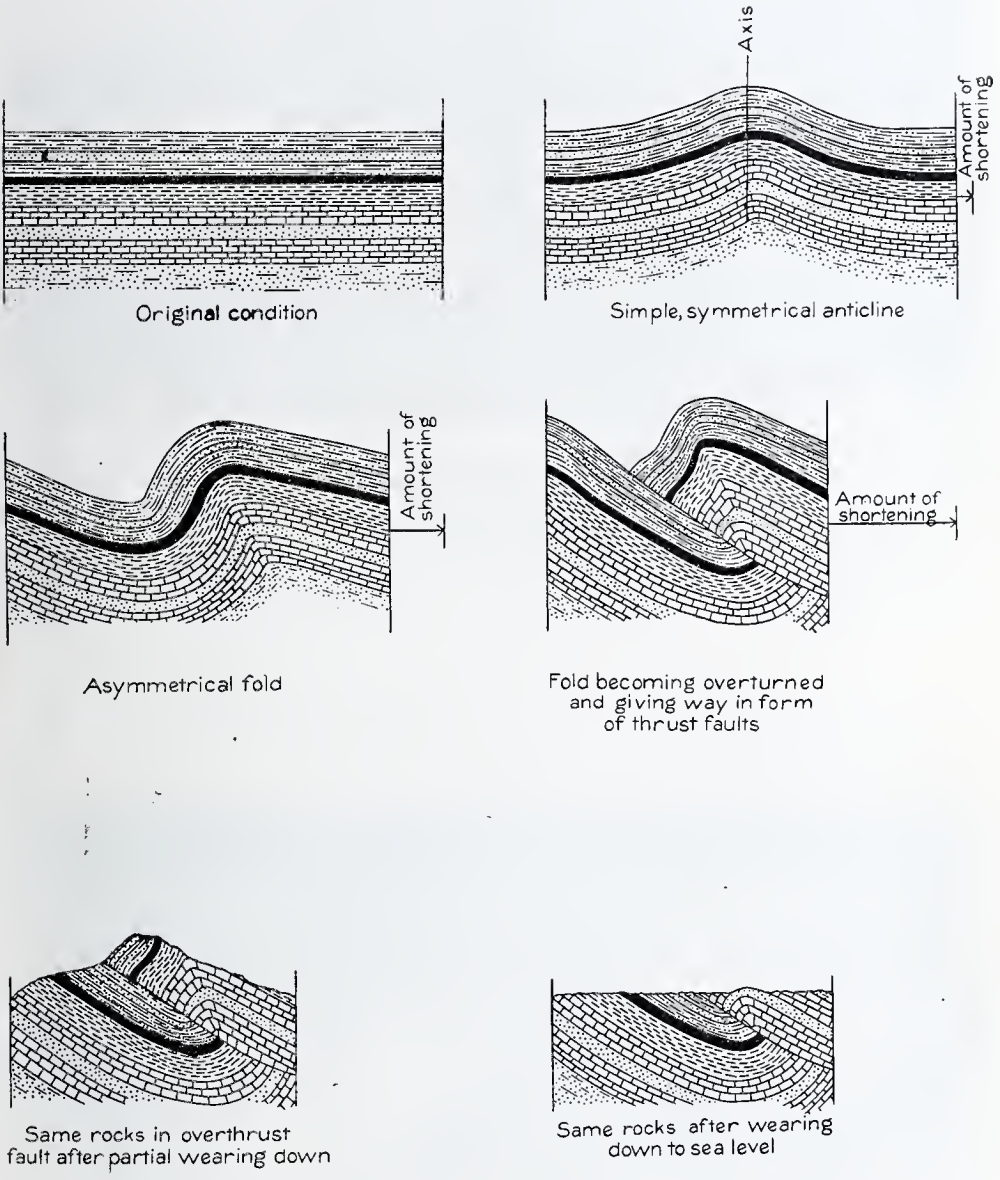

Original condition
Axis
Amount of shortening
Simple, symmetrical anticline
Amount of shortening
Asymmetrical fold
Amount of shortening
Fold becoming overturned and giving way in form of thrust faults
Same rocks in overthrust fault after partial wearing down
Same rocks after wearing down to sea level

Fig. 17. Diagram showing development of a thrust fault and the corresponding amount of shortening of the strata due to the folding and faulting.

Fig. 18. Thrust fault (along diagonal plane below grass and shrubbery) on Juniata River near Birmingham, in which the beds below the diagonal line of faulting belong stratigraphically 4,300 feet above the beds above the line of faulting.

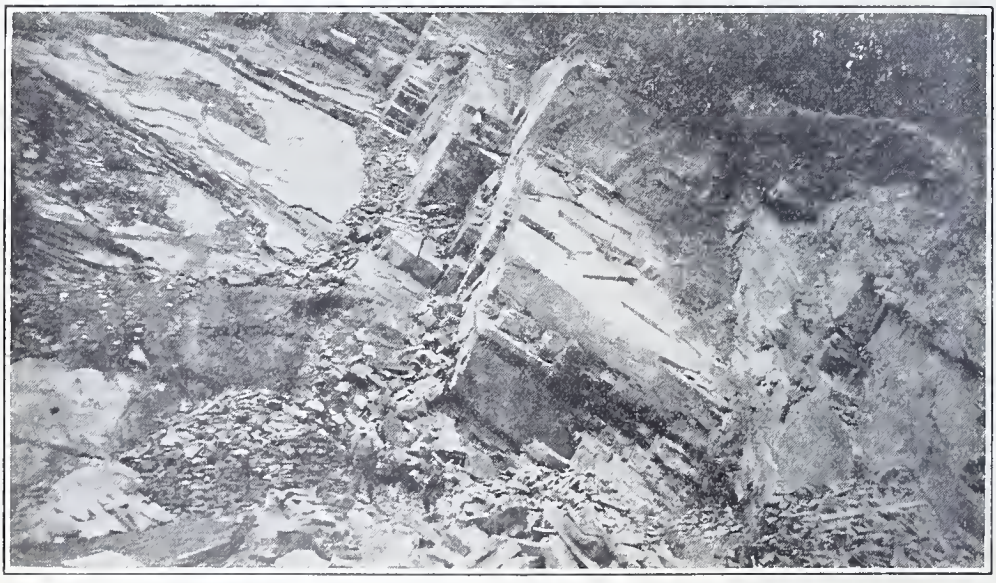


Fig. 18a. Jointing in fine-grained sandstones, Avondale, Chester County. Photo shows large bedding planes (facing top and right), face joints (facing upper left corner) and butt joints (facing reader).
Photo by R. W. Stone.

The diabase or trap so abundant in the area of Triassic sediments in Pennsylvania has weathered deeply, and the surface under which it lies is covered with soil or strewn with residual blocks. Exposures of the contact between the trap and sediments are rare but these intrusions are believed to be dikes and sills. The granite near Allentown and the granite, gabbro, and other granitic rocks near Philadelphia are the tops of irregular masses exposed by the erosion of overlying beds.

Mineral deposits. Mineral deposits are local accumulations or concentrations of useful minerals. Some deposits occur in more or less regular beds, as bog iron ore, originally deposited in swamps. When minerals are found in the sands and gravels of streams or other bodies of water they are called "placer" deposits, as gold, diamonds, magnetite, many gem minerals. These bedded deposits are the result of erosion, disintegration, transportation, and redeposition of the transported material. Transportation by wind or water tends to grade, sort and segregate minerals, specific gravity being an important factor. Also, animals, plants and chemical processes working together effect the accumulation of some minerals in valuable bedded deposits, as some manganese deposits.

Commonly cracks or crevices are filled with minerals deposited principally by precipitation from solution. These are called veins. The solutions may be descending surface solutions or ascending hot solutions. Where two or more veins meet, there is frequently a rich concentration of the minerals called a "bonanza." A large fracture zone consisting of more or less parallel veins irregularly connected is called a "lode."

Mineral deposits may be formed by concentration of certain minerals in a cooling mass of molten rock or in the adjacent country rock. Such bodies are usually irregular in shape. The minerals are frequently disseminated over an irregular area adjacent to the igneous mass, called a contact deposit.

Surface water contains carbon dioxide and tends to disintegrate the rock with which it comes in contact by dissolving out the more soluble minerals. The removal of the soluble minerals may leave behind a concentration of less soluble material, as when limestone is dissolved and a residual deposit of limonite formed. These deposits are irregular in extent and shallow.

Other means of accumulating mineral deposits are erosion, disintegration, transportation, and redeposition of the transported material. Transportation by wind or water tends to grade, sort, and segregate minerals, gravity playing a strong part, and results in bedded deposits. Also animals, plants, and chemical processes working together effect the accumulation of some minerals in valuable deposits.

Usually the ore or valuable mineral in veins is associated with quartz or some other gangue mineral that fills the crevice. Other ore bodies may be replacements of country rock, as when a solution rising along a crevice dissolves out limestone and leaves iron ore in its place, as occurred at Cornwall. Many ores occur where hot igneous rock has come in contact with, and metamorphosed another rock. In this case the ore brought in by the hot magma usually spreads out through the altered rock.

Uplift and depression. Casual reference has been made to movements of the earth's crust. It is a well known fact that the surface crust of the earth is perhaps never still with reference to sea level, but always rising or sinking. This is best seen along the seacoast where reference to sea level is easy. In other places former lakes have left old shore lines that are not level now, thus indicating recent crustal tilting. Sand and gravel deposits of recent origin near Lake Champlain contain bones of whales and walrus. Evidently that area at the time those deposits were formed was under the sea and at least 600 feet lower than at present. On the contrary, the Hudson River in its lower course is flowing over a deposit of silt, sand, and gravel several hundred feet deep, and surveys of the Atlantic coast show that old river channels extend from New York harbor and other bays across the Continental shelf for 100 miles or less out to sea. Evidently not long ago, the land stood many hundred feet higher than today, and during that time the Hudson River cut its channel to its present rock bed. The rugged coast of Maine is due to the sinking and flooding of valleys and hills along that coast. Delaware and Chesapeake bays are sunken valleys, but close by, the Falls of the Potomac, give evidence of very recent uplift. Evidently the river had been established about at sea level, then the region was uplifted and the river flowed rapidly down the new slope, cutting a channel that today is eating back by means of a waterfall. The lower Susquehanna has a gradient of nearly 6 feet to the mile. Above Columbia the grade is only a little over 2 feet to the mile. There it looks as though there had been recent uplift, and the river in its lower valley is starting to establish a new gradient at a lower level.

Sea shells occur several thousand feet above sea level imbedded in the rocks of our highest mountains. Obviously not only are movements of elevation and depression going on, but they have been going on indefinitely in the past. It was pointed out that the rocks in Pennsylvania contain evidence of having been deposited in very shallow water. As these rocks have a thickness of 30,000 feet or more, we can explain these facts only by assuming that they were deposited in a shallow sea whose bottom was slowly sinking, and that this sinking continued to the extent of 30,000 feet or more. Along the Pacific coast, the evidences of recent movement both up and down are very clear.

Earthquakes. Earthquakes are commonly associated with these movements in the earth's crust, though earthquakes also accompany volcanic eruptions. In many instances after an earthquake a block of the earth's crust whose movement caused the earthquake is found to have been distinctly lifted or depressed, sometimes making a small cliff or an escarpment along the line of break. A region of frequent earthquakes is almost certainly in active motion. Consequently where recent faulting is found, earthquakes may be expected. Pennsylvania as a whole has been remarkably free from severe earthquakes in historic time. There appear to have been more in the Philadelphia area, than elsewhere. They may be connected with crustal movements in that area that may be still in progress.

Volcanoes. Pennsylvania has no active volcanoes today, but in the past has been the scene of considerable volcanic activity. Most of this

activity has been in nature of upflows of igneous rocks through the other rocks. Of the igneous rocks to be seen today in Pennsylvania most appear to be either sills that pushed out between the beds of other rocks, or vertical dikes. Some of the igneous rocks appear to have been lavas originally, though now considerably changed. A number of layers of a clay-like substance called bentonite, and known to have been volcanic ash are found among the rocks of Pennsylvania and show that there have been active volcanoes either in or near this State at different times.

Rock folding. Few places in the world show better evidence than in Pennsylvania of those titanic forces that, seeming to compress the earth's crust horizontally, have folded, broken, and crumpled the rocks composing that crust to a depth of tens of thousands of feet. This evidence has already been presented under rock folds and faults. The exact cause of this folding and faulting is not known, though it is the subject of very intensive studies and discussions at the present time. The old theory which many still hold is, that the interior of the earth is shrinking in size, while the crust, which continues at the same general temperature, is not. Therefore, just as an apple in drying up becomes wrinkled, so the interior of the earth shrinks by loss of heat, and the earth's crust, continually settling down, becomes wrinkled and cracked.

In this connection attention may be called to four features of such rock folding as occurs in Pennsylvania. (1) The folding and faulting involve a considerable amount of shortening. Estimates of shortening across the strata from Altoona to Harrisburg differ between 15 and 60 miles. The writer has estimated that the whole shortening between Altoona and Philadelphia may be as much as 100 miles. If the western part of the State stood still when the folding took place, then the eastern end originally may have been where is now the Atlantic Ocean. (2) Folding occurs characteristically where there has been profound crustal sinking and heavy sedimentation. Just as the folding of the Appalachian region occurs where sedimentation was heaviest, amounting to 30,000 feet or more of rock, so in other places on the earth's surface folding is usually associated with very heavy sedimentation. As yet no adequate explanation of this relation has been offered except to suggest that the sinking of the original sea bottom has carried the rocks into a zone of higher temperatures, and, thus, softened and weakened, rendered them susceptible to crushing and folding. (3) Folding must have involved large upward movement, and for a time probably produced a high, mountainous surface. While it is true that such folding probably was very slow, so slow that erosion made large inroads on the rising folds, yet, if we may judge by the Alps, Andes and Himalayas, which are young, fresh mountains, erosion did not characteristically keep pace with the uplift, and high mountains resulted. (4) Many of the present high mountains of folded rocks are due to uplift following the wearing down of the previously high folds; that is, such mountains as the Sierras did not get their present elevation from the height of initial folding, but the original folds having been worn down, recent elevation has given the mountains their present height. The mountains of Pennsylvania obtained their height as the result of quite recent uplift of the whole State.

Just as water follows a cycle from the sea to the clouds, to the earth, and back to the sea again, so rocks and rock material follow a cycle. Rocks in the hills and mountains broken up by wind and weather. Running water, the great carrier, removes the fragments and transports them down to the sea, where they are deposited. In time this material becomes hardened into rock and then titanic earth forces raise this rock again into mountains or hills.

Wind and weather. Wind has little direct effect as a geologic agent in Pennsylvania, though in other and dryer lands it may transport fine sand or dust long distances and even erode rock with them. Rain, heat, and frost are active geologic agents. Heat from the sun expands rock and disrupts it. Water getting into the crevices of the rock freezes and expands, splitting off small or large pieces which are carried

Fig. 19. Decay of rock into soil. Note how the solid rock below disintegrates toward the surface where only the less soluble portion remains as a sandy clay soil. Photo by R. W. Stone.

down the hill slope by rain. In many countries rain in itself is an eroding agent of considerable importance. Probably more important than either rain or frost is underground water which becomes charged with carbonic acid in its passage through the air, and with humic and other acids in soaking down through the soil. So charged it becomes an active agent in dissolving rocks. Such waters attack and make the rock decay, breaking it down into soil, in which conditions it is of value to us in agriculture and is ready to be carried away by running water.

Ground water. Water penetrating the ground in part accumulates in the crevices and pore spaces in the rock up to a certain level called the "water table." In part it flows out at springs. The water table is further from the surface under the hills, than under the valleys. Indeed it is likely to touch the surface in the valleys, yielding springs

at those points. The level at which water stands in wells marks the water table. Of wells which reach the water table, the best flow is obtained from coarse-grained rocks like sandstone or conglomerate in which there may be from 10 to 30 per cent of open pore space. Wells in shale usually yield only a little water, if any. Wells in limestone, granite, or the fine-grained rocks may yield little or no water, unless cracks or crevices are penetrated through which water may flow.

Underground waters entering the joints in limestone and dissolving the rock on either side may ultimately remove the whole bed. (See Fig. 21). Limestone areas commonly form valleys or lowlands, in some places yielding quite as readily as shales to the forces of erosion.

Fig. 20. Limestone bed stripped of soil, showing pitted and irregular surface, the effect of solution. Quarry near Billmeyer, Lancaster County.

Caves. In this connection may be mentioned the caves that today are attracting much attention. Water entering a thick limestone bed tends in its movement to dissolve channels that may in time enlarge themselves into passages or rooms often of considerable size. If later the level of ground water is permanently lowered and air fills the channels, then water seeping through the roof may dissolve a little lime and entering these passages or rooms, evaporate and deposit the lime on the top or bottom of these passages as stalactites and stalagmites.

Rivers and their valleys. Under the influence of rain and frost, rocks tend to break up and then to creep down the hillside, either as soil or as blocks of all sizes. Large blocks tend to clog stream channels. In time of flood they are carried along, becoming rounded as they pound on other rocks, or on the river bed. In time these rocks are ground down to sand, and meanwhile they have helped to widen and deepen the river channel.

A normal river goes through the stages of youth, maturity and old age. In youth it is rapid, and its valley is narrow with precipitous

sides in many plaees. There may even be waterfalls. These charaeteristics always imply youth. In time, if the land does not rise or sink the bed of the river is cut down until the eurrent is slower and the valley widens. The waterfalls disappear, the slopes beeome gentle, and the valley is said to be mature. Given more time a river becomes sluggish and no longer deepens its channel, but, swinging sidewise, widens the valley. When the interstream area is so low that there are only plains either side of the valley, then the river is "old." As a matter of fact so active are the internal forces of the earth that usually before a river reaches old age something happens that renews its youth, changes its course, or buries it in the sea. It is beeause of the aetive earth movements in Pennsylvania that today there are no old valleys in this State, though, as we shall see, there have been old valleys which now are recorded only as flat tops of hills or mountains. An uplift of the land

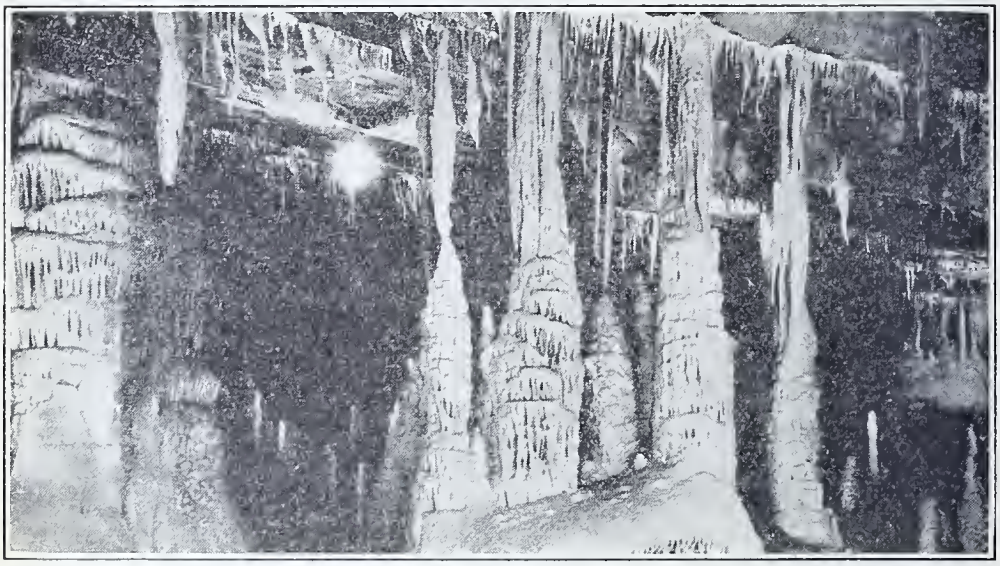
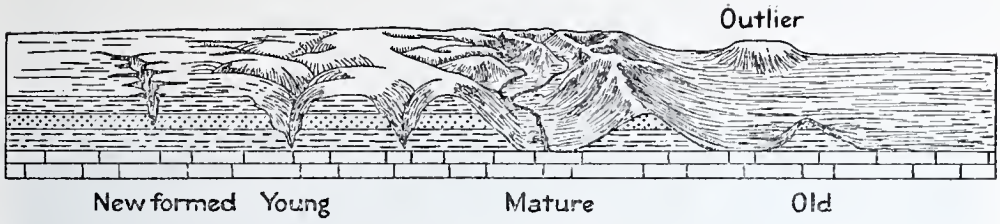


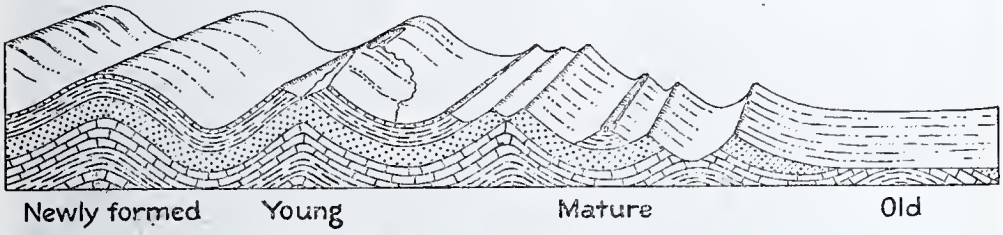
Fig. 21. View in a Mifflin County cave.

at the river's head increases the grade and starts renewed downward cutting. An uplift near its mouth decreases the grade of the river and may even pond its waters. Where there has been uplift and renewed downcutting, there may be waterfalls and cascades. These wear back rapidly and disappear. The many waterfalls of Pennsylvania date back only a few thousand years.

Glaciers. Another force that has played a large part in Pennsylvania is moving ice. Ice forming in rivers or lakes may shove or dig into the banks when it breaks up in the spring or is driven by floods or winds. But in times past and in many now-existing mountains snow has aecumulated to a depth of hundreds or even thousands of feet and turned to ice. Such bodies of ice, called glaciers, yield under pressure of their own weight, and flow away from the place of greatest depth. As a glacier moves, it does several things. If formed in high mountains it tends to pluck away the rock on which it rests, forming a huge bowl with perpendicular sides, called a "cirque." Such glacial plucking has made the slender crags and pinnacles of the Alps and other high mountains. As it advances a glacier gathers up loose soil and rock and



A, Topographic cycle in horizontal rocks.



B, Topographic cycle in folded rocks.

Fig. 22. Sketches showing the changing contour of the surface as, with time, it wears down. The general wearing down process is affected by the hardness of the rocks.

Fig. 23. Scene in Greene County where erosion has produced the general contour of mature valleys because the rocks are mostly shale. Probably these valleys are no older than the much narrower valleys of northwestern Pennsylvania where hard rocks have prevented much widening.

Photo by R. W. Stone.

Fig. 24. Waterfall on Bushkill Creek. Falls are a sign of recent uplift or diversion, for they continually wear backward and in a relatively short time may bring the valley to grade and disappear. Pennsylvania has many fine waterfalls in the Pocono region. Photo by Pennsylvania Highway Department.

plucks out fresh rock. This material carried along under the ice tends to wear down the surface over which the glacier passes. Thus a valley may be worn down to a deep U-shape leaving the old side valleys high in the air. Such side valleys are called "hanging valleys." In shale areas a glacier may deepen valleys so that they become basins for lakes, such as the lakes of central New York and Lakes Ontario and Erie. A glacier smooths off rough places, leaving on hard rock a polished surface, and scratches showing the direction of its motion. Such places are found abundantly in northeastern and northwestern Pennsylvania. (See Fig. 25).

Part of the material carried forward by a glacier is dropped in valleys it crosses, part is left as a moraine along the line where forward movement stops and retreat begins, and part is spread out as a blanket in its retreat, producing an irregular surface of glacial till

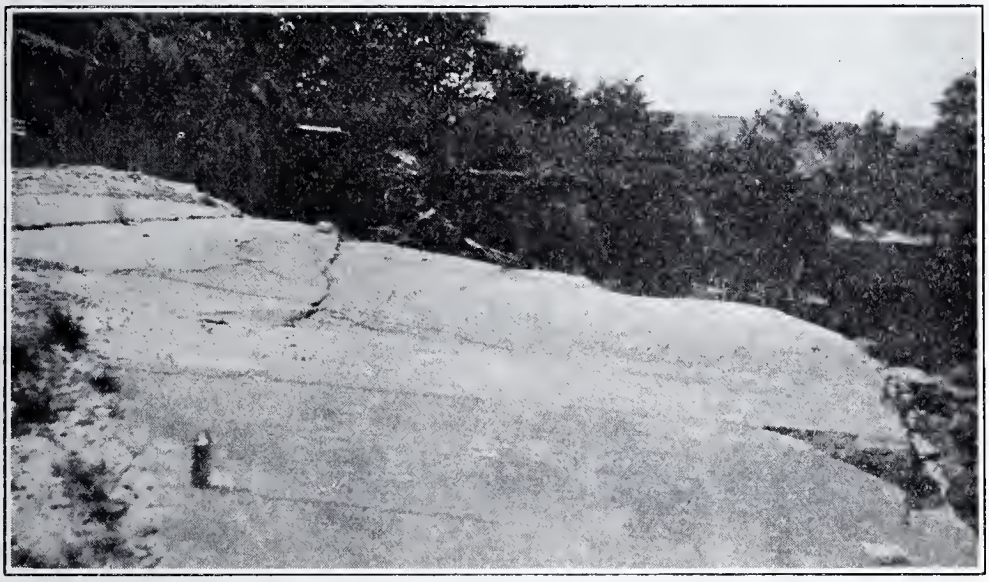


Fig. 25. Glacial polishing and scratching. A rock surface over which a continental glacier has pushed, not only removing all the loose surface rock but wearing away and rubbing smooth the underlying hard rock. Top of Penn Silicon Company quarry, Meadville, Crawford County. Photo by R. W. Stone.

composed of rock flour mixed with bowlders, sand, gravel and clay. See Fig. 66. These deposits are distinguished from water-laid deposits in that the glacial bowlders or rock fragments are less smoothly rounded than water-worn bowlders, and are often flat-sided and scratched where they have been held in the ice and pushed over the rock on which the ice was moving. They also differ in not being sorted as to size or material, and they lack bedding. Finally they differ in most places in containing rocks that do not occur in the river basin where found, but must obviously have been brought into the basin from some distance, usually from the north.

Sedimentation. A river must deposit its sediments somewhere. Some of the material is deposited on the flood plains during high water; some is left in channels abandoned as the river cuts new channels in swinging from side to side. Most of it, however, is carried

to the mouth of the river and into the sea, and there spread over the beaches and sea bottom by waves, tides, and currents. The coarse material is left on or near the beach, the finer material is spread farther out. Most of it is left within 10 miles of shore. If, however, the land along the shore is rising, the beach and shallow water steadily advance seaward, each carrying its characteristic deposit with it. In this way fine and coarse sediments may spread as far as the shore advances, the coarse sediments forming a layer over the fine sediment. If the shore retreats, this process is reversed. The occurrence of alternating widespread layers of coarse and fine sediments is explained on the basis of intermittently rising and sinking shores.

Plains. Plains are made in several ways; all however, are related to some water level. Thus, elevation of the sea bottom above water forms a raised sea plain. This uplift may go so far that the raised sea plain is several thousand feet above sea level, as are the Great Plains of our Western States. A plain may be made by filling up a lake or shallow sea, such as the plains at the heads of the lakes in central New York, as at Ithaca, N. Y. A plain may be formed by erosion to a temporary base level or to sea level, through the action of streams or waves. An erosion plain, called a peneplain, is seldom as level and smooth as one formed by uplift of sea bottom.

Plateaus. If a plain, whether of erosion or of raised sea deposits, is uplifted to a considerable height, water running off soon begins to cut deep channels or valleys. So long as the plain predominates over the valleys, the region is called a "plateau." If the plateau is underlain by hard, flat lying rocks, the valleys are gradually widened until only small remnants of the old plateau remain. In the West such remnants are called "mesas." If the plateau is underlain by the edges of folded rocks, some soft and some hard, erosion will progress much faster in the areas of soft rocks which soon become valleys, while the hard rocks remain standing as residual mountains.

Fossils and What We Learn From Them.

What fossils are. Besides building stones, clay, coal, salt, iron ore. oil, gas and many other valuable things, the sedimentary rocks of Pennsylvania contain fossils. These are the evidences of the former presence of animals and plants that lived on land or in water, or were washed down into the sea and buried and preserved in the accumulating sand, mud or lime. Fossils may be the actual limy matter of shells or bones or the lime may have dissolved out leaving only an empty impression or one filled with other material.

Where found. Pennsylvania has few fossils as compared with some other States. Many of the waste-rock dumps at the coal mines contain fossil plants. Most limestones and some shales of western Pennsylvania contain fossils. Sharp eyes will find fossils in many of the rocks of central Pennsylvania. The very old rocks south and east of the Kittatinny Mountains contain very few fossils.

Their value. Fossils enable us to identify rocks of the same age, for the same fossils occur commonly in the same bed or equivalent beds from New York to Alabama, but differ in part or in whole from the

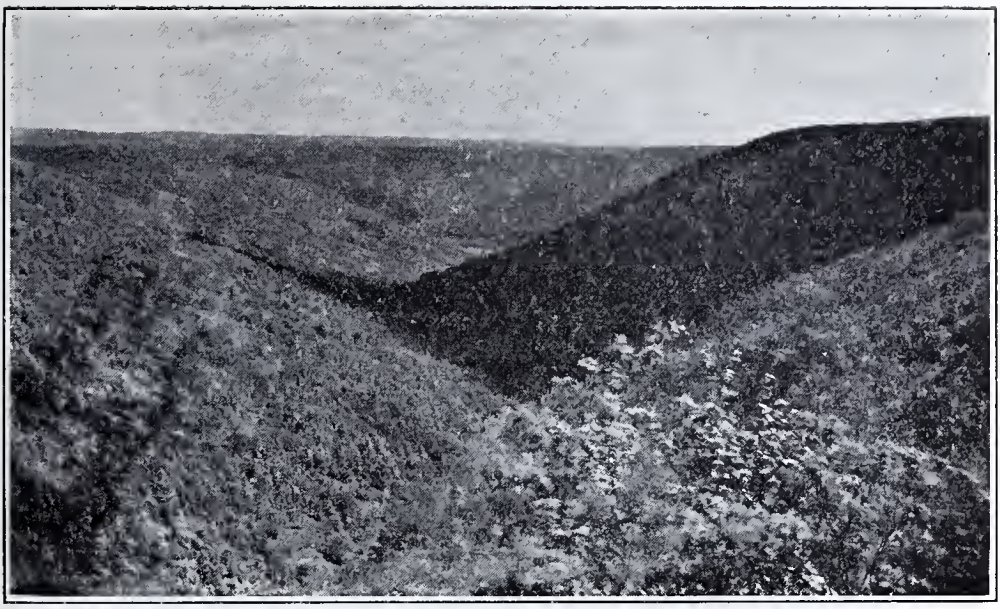


Fig. 26. Plateau of Potter County. A plain of erosion now being reduced to a new lower level. The level top of the plateau is maintained by the hardness of the underlying rock. Compare with Figure 23, where the rocks yield more readily to erosion. Photo by Pennsylvania Department of Highways.

Fig. 27. View of the Vallemont region of central Pennsylvania, Juniata County. The long ridges in the background are formed by the upturned edges of hard rocks that have resisted downcutting. Evidently the rock (Medina) in the distant mountain is much harder or thicker or both than the hard layer in the Upper Silurian forming the ridge in the middle distance. Cedar Grove Valley, Mifflintown.

fossils in the beds above and below. Geologists have collected and compared fossils from so many places that today it is generally possible to tell from just where in a table showing the succession of all known rocks a given set of fossils came. We can tell whether most of the sedimentary rocks in Pennsylvania are older or younger or of the same age as other rocks anywhere in the world. This makes it possible to fit together geological information from all over the world and to work out a connected history of the rocks, lands, seas and climates of all past time.

Fig. 28. Fossils (shells of brachiopods) on slab of rock from Susquehanna County. Photo by D. S. Harding.

A geological time scale. In order to talk about different beds of rock each bed is given a name, usually of a place where well exposed; as, Pittsburgh coal bed, Pottsville sandstone. Two or more beds taken together are called a "group," several groups make a "series," and three series a "system." All the rocks in a system were laid down during a "period" of time. Two or more periods make an "age," two or more ages an "era." The following table, referred to in all subsequent chapters, gives the eras, ages, periods and systems in use by the Pennsylvania Geological Survey.

Table of Rock Systems.

Eras	Ages	Periods	Systems	Average thickness of rocks by systems (in feet)	Maximum thickness of rocks in world (in feet)
	Quaternary	15th	Quaternary		
Cenozoic	Tertiary	14th	Upper Tertiary	5000	30,000
		13th	Lower Tertiary	5000	20,000
	Cretaceous	12th	Upper Cretaceous	5000	19,000
		11th	Lower Cretaceous	4000	26,000
Mesozoic	Jura-Trias	10th	Jurassic	3000	10,000
		9th	Triassic	5000	29,000
		8th	Upper Carboniferous	3500	13,000
	Carboniferous	7th	Middle Carboniferous	4500	24,000
		6th	Lower Carboniferous	2000	7,000
Paleozoic	Siluro—Devonian	5th	Devonian	5000	15,000
		4th	Silurian	3000	7,300
		3rd	Ordovician	3000	15,000
	Taconic	2nd	Canadian	3000	14,000
		1st	Cambrian	5000	28,000
			Pre-Cambrian (in Pa.)	10,000	80,000

Unfolding life. If fossils from all the world are arranged in the order of the rocks one above another, a marvelous procession or unfolding of life appears. In Taconic rocks are found only water plants and animals without a backbone. In Silurian time fish become common, and in Devonian time the first amphibians. In late Carboniferous time reptiles arrive. In the Mesozoic era reptiles dominated land and sea and air. During this time the first birds and first mammals appeared, but they did not become important until Tertiary time when the great reptiles had disappeared. Finally in the Quaternary, man became the dominant life form.

Not only did higher and higher forms appear with time but the lower forms were constantly changing, old forms dying out and thousands of new forms coming in, the new quite obviously developing out of the old.

The Beginning of the Story.

The origin of the earth. How did the earth begin? What we know of the earth, the sun and other stars and planets leads to the theory that, billions of years ago, a great star passed near our sun, then semi-gaseous, attracting out and drawing after it a long streamer of sun-matter. But the star passed on and this sun-matter, left floating in space, began to cool and gather at points of greater density into lines of semi-dense bodies that in time became the nuclei of the earth and other planets. Some collected as minute particles already cold, like

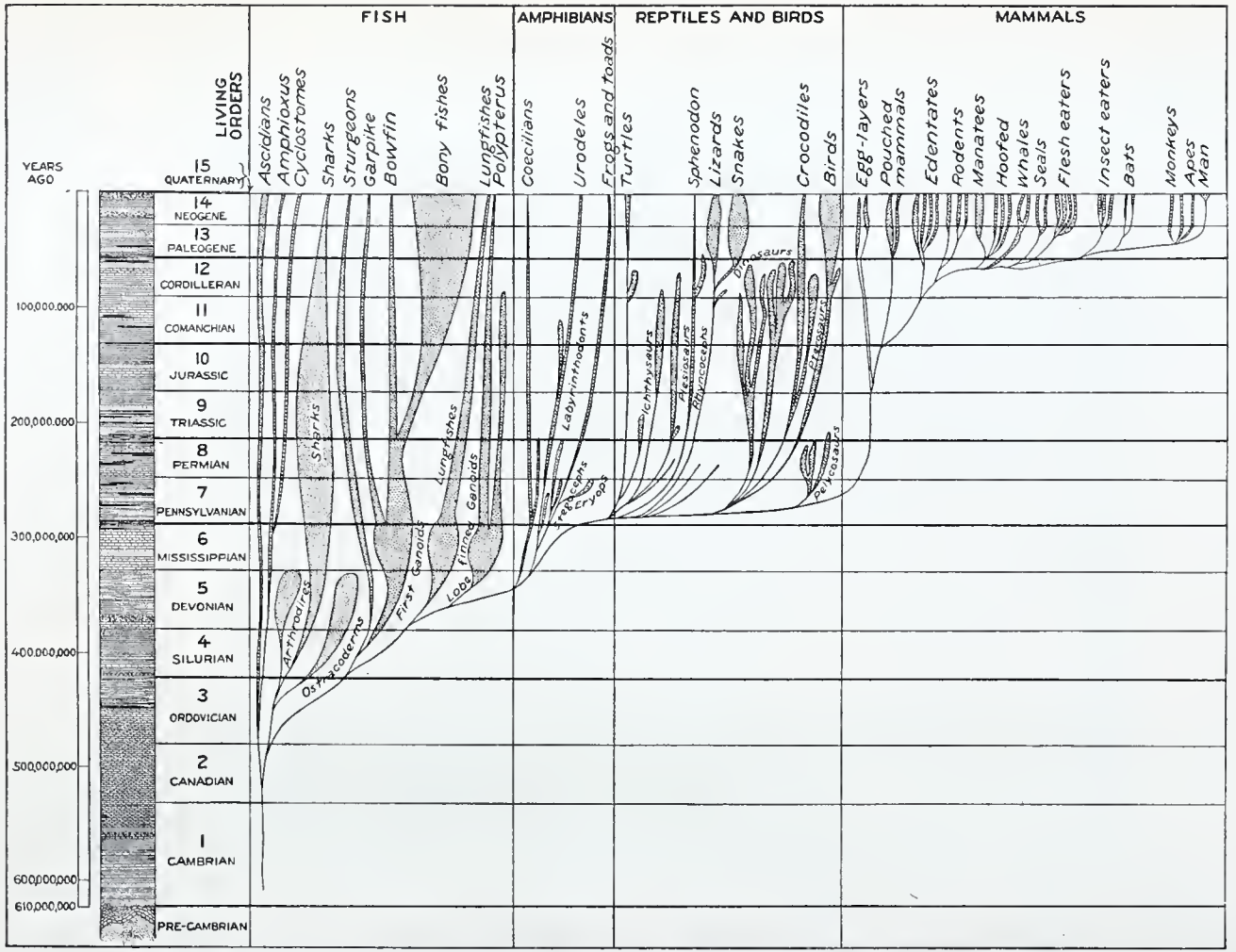


Fig. 29. Chart showing the successive appearances of the principal orders of vertebrate life. After Gregory.

the shooting stars, some in large masses. It has been suggested that the moon was a mass so large that instead of falling into the earth it missed and began to revolve about it. Because gathered thus the earth is not uniform in shape, weight or composition, differences that may account for deep oceans here, high lands there, and the varied history told by the rocks. Condensation and continued infall of meteors, with increasing temperature, followed; and then the surface partly cooled.

The earth today. The earth today has (1) a thin crust of common rocks 30 to 60 miles thick, with an irregular surface, mostly covered with water; (2) a zone of plastic rocks (basalt), high in iron, where heat and pressure are so evenly balanced that change of pressure starts flow movement, as in quicksand. This basalt sometimes comes to the surface, as in the trap rocks of southeastern Pennsylvania and in the vast lava beds of Oregon and Idaho; (3) a great central core, very heavy, inconceivably hot, more rigid than steel, probably of nickel-bearing iron.

The beginning of sedimentation. When the original igneous rocks exposed at the surface began to break down by weathering, the quartz grains became sand, and feldspars, micas and similar minerals weathered into clay; the lime dissolved out. These, washed into water areas, became sandstone, shale, and limestone.

Beginning of life. Somewhere in this process life appeared on the earth. Just how, nobody knows. Some have suggested it came from another planet. Most scientists, however, feel that somehow the potential capacity for life existed in the so-called non-living earth and only needed suitable conditions to be expressed in living matter. This first life was probably microscopic and very simple, just protoplasm without even cell wall or nucleus. All remains of it have since been destroyed in the subsequent extreme crushing and heating of the rocks. Thousands of feet of rocks were laid down and life had unfolded into a great variety of the lower forms before conditions allowed the preservation of fossils. We call this early time the Pre-Cambrian.

Stratigraphic Scale and Rock Section for Pennsylvania.

The following table serves a double purpose. First, it gives an expanded time scale showing, in addition to the systems and periods of the preceding table, insofar as they occur in Pennsylvania, the series, which are the primary subdivision of a system, and groups, which are the primary subdivision of a series. A "series" of rocks comprises the rocks laid down during an epoch of geologic time. Each period is assumed to be divisible into three epochs designated, Early, Middle and Late. The corresponding series are called Lower, Middle and Upper with the system names. Each epoch is assumed to be divided into three units, (9 for each period) which, because designated by decimal numbers, are called decims. A "group" is the body of rock or rocks laid down during a decim of time. Groups are named in two ways; (1) by number, using a combination of the number of the period and of the decim as 43 for the group laid down during the third decim of the fourth period; (2) more commonly groups are named from some locality.

Second, the table helps to tie the new geologic map of Pennsylvania to this descriptive bulletin, for the "Group Code" and the "Second Survey Code" repeat the letter or number symbols used on the map.

The table also shows the correspondence between the rock divisions made by the First and Second Geological Surveys and those standard today.

There has long been differences of opinion as to the age of the Lower and Middle Medina. Many hold that the Lower, and some that both the Lower and Middle Medina are of Ordovician age. Many facts point that way. However, until further studies settle the problem one way or another the writer has followed the Second Geological Survey and the New York State Survey in keeping the three parts of the Medina together and treating them all as Silurian. Many problems of this kind will be discussed more at length in the bulletin on "The Rocks of Pennsylvania," now in preparation.

In general, disputed points of age or correlation are left for discussion in the later paper just mentioned. It is hoped that by the time that bulletin is issued additional information will permit definite decisions on many of these questions.

In several places where only one name appears in the table of groups, several names may be used on the State map or may have been used in former reports. Some of these will be referred to in the descriptive tables that follow. In general the writer has sought in the interest of simplicity to adopt and use one name for all formations laid down during each decim of time, after which names of subdivisions may appear in parenthesis, or synonyms may appear between quotation marks.

Pre-Cambrian Rocks in Pennsylvania.

Two systems of pre-Cambrian rocks are exposed in southeastern Pennsylvania. The older system, called the Baltimore gneiss (Archean time), the oldest rocks in the State, was undoubtedly laid down as sediments. But folding by mountain-making forces and intrusion from below by melted rocks have changed them almost to granite. Uplift and erosion were followed by submergence. Then 10,000 feet of sand, mud and gravel were laid down—the Glenarm series (Algonkian time). Later these in turn were folded and crushed, intruded by igneous rocks, uplifted and worn down, then sunk below sea level. In the folding and crushing they were changed mainly into schists, quartzites, marbles and slates. Marble and graphite in these rocks are thought to bespeak life in that day.

Today these rocks supply building stone—granite, gneiss, marble, schists, slate and other rocks; many valuable minerals, produced during the folding and crushing—feldspar, talc, serpentine, garnet, soapstone, chromite, graphite; and many crystallized minerals. See figures 30 to 33, all by Mr. Stone.

In South Mountain between Adams and Franklin counties the Paleozoic rocks lie not on the Glenarm series but on igneous rocks of the same age consisting of red or purple rhyolite and green basalt. Both have been metamorphosed from their original character as glassy lavas.

GEOLOGIC TIME SCALE.

Penna. Geological Survey — Standard Section: Eras	Periods Systems	Epochs or Series	First Geol. Survey of Penna	Second Geol. Survey of Penna	Groups and formations by number (time scale) and name (source & date) [small letters refer to members]	Group Symbol	Maximum thickness: Eastern district	Central district	Northeast district	Southeast district	U.S. Geol. Survey: Series	Systems	Eras
CENOZOIC	Quaternary	Recent			152 Alluvium	Qa	100				Recent	QUATERNARY	CENOZOIC
		Pleistocene			151 [d Late Glacial; c Early Glacial; b Cape May N.J. 1897; a Pensauken N.J. 1894]	Qw / Qpw / Qp	80			40 / 30	Pleistocene		
	Tertiary: Fourteenth or Upper Tertiary	Pliocene / Miocene			149? Bryn Mawr, Pa. 1880 — not represented	Tbm				50	Pliocene / Miocene	TERTIARY	
	Tertiary: Thirteenth or Lower Tertiary	Oligocene / Eocene									Oligocene / Eocene		
MESOZOIC	Cretaceous: Twelfth Per. or Upper Cretaceous										Up. Cretaceous	CRETACEOUS	MESOZOIC
	Cretaceous: Eleventh Per. or Lower Cretaceous			Potomac	148? Patapsco, Md. 1857	Kp				740	Low. Cretaceous		
	Jura-Trias: Tenth Per. or Jurassic				not represented						Up. Jurassic / Mid. Jurassic / Low. Jurassic	JURASSIC	
	Jura-Trias: Ninth Per. or Triassic	Upper Triassic or Newark (N.J. 1882)	Mesozoic Red Sandstone	Triassic or Newark "New Red"	Diabase (intrusive)	Td					Up. Triassic	TRIASSIC	
					39 Brunswick, N.J. 1857	Kb				12400			
					40 Lockatong, N.J. 1857	Kl				3500			
					41 Stockton, N.J. 1857	Ks				6100			
		Mid. & Low. Triassic			36 / 37 not represented						Mid. Triassic / Low. Triassic		
PALEOZOIC	Carbon.: Eighth Per. or Permian	Upper Permian			43 / 45 not represented						Permian	CARBONIFEROUS	PALEOZOIC
		Dunkard (Pa. 1858)	III	III Greene Co.	42 Greene, Pa. 1878	Cg	2400	Eroded	Eroded				
			III Upper Coal	III Washington Co.	41 Washington, Pa. 1875	Cw	400						
	Carbon.: Seventh Per. or Pennsylvanian	Pittsburgh (Pa. 1839)	IV Upper Coal Measures	IV Monongahela River Coal Measures	79 Monongahela, Pa. 1840	Cm	400			500	Pennsylvanian		
			IV Lower Coal Measures	IV Pittsburgh Coal Bed / Allegheny River Coal Measures	78 Conemaugh, Pa. 1878	Ccm	650	900		1550			
					77 Allegheny, Pa. 1840	Ca	370	300		350			
		Pottsville (Pa. 1877)	III Serpent Mountain Conglomerate	III Pottsville	76 Pottsville, Pa. 1877	Cpv	400	280		1400			
	Carbon.: Sixth Per. or Mississippian	Chester (Ill. 1857)	III Umbral	III Mauch Chunk	75 Mauch Chunk, Pa. 1877	Cmc	150	1000		2200	Mississippian		
		Meremec			46 Shenango Conglomerate (Loyalhanna) 1857 1905 / 45 / 44 not represented	Cl	60	80		0			
		Waverly O. 1838	II Subperfect	II Pocono	43 Pocono [c Thompson, Pa. 1905; b Cuyahoga O. 1870; a Berea, O. 1870]	Cpe	750	1400		1100			
	Devonian: Fifth Per. or Devonian	Upper Devonian	II Parent	II Catskill	53 Catskill, N.Y. 1842	Dck	7000?	2500		7000	Up. Devonian	DEVONIAN	
				Chemung	52 Chemung, N.Y. 1838	Dch		3300					
				Portage	51 Portage, N.Y. 1840	Dp		1800					
				Genesee	50 Genesee, N.Y. 1841			?					
		Middle Devonian	VII Calent	Hamilton	55 Hamilton, N.Y. 1839	Dhm	2750	1200		2375	Mid. Devonian		
			VII	Marcellus	54 Marcellus, N.Y. 1838			150		800			
				Corniferous	53 Onondaga, N.Y. 1836			50					
		Lower Devonian	VII Meridian	VII Oriskany Sandstone	52 Oriskany, N.Y. 1839	Do		400		300	Low. Devonian		
			VI Pyramidal	VI Low Helderberg Limestone	51 Helderberg, N.Y. 1836	Dhb		150		600			
	Siluro-Devonian: Fourth Per. or Silurian	Salina (N.Y. 1841) "Cayuga"	V Solent	V c Salina	49 Tonoloway, Md. 1892	Ss	500	600				SILURIAN	
					48 Wills Creek, Md. 1892		2000	400					
					47 Bloomsburg, Pa. 1885			450		1200			
		Niagara (N.Y. 1842)		V b Niagara	46 Lockport, N.Y. 1838	Sr		1400					
				V a Clinton	44 Clinton, N.Y. 1841			1200		1000			
		Medina (N.Y. 1842)	IV Forest	IV a "Oneida" b Medina	43 Tuscarora, Pa. 1877	Sl		600		1200			
					42 Juniata, Pa. 1857			850		0			
					41 Oneida, N.Y. 1841			800		0			
	Cambro-Ordovician: Third Per. or Ordovician	Cincinnati (O. 1859)	III Natural	III b Hudson River Shales / III a Utica Shales	39 Pulaski, N.Y. 1843	Hudson River					Up. Ordovician (Cincinnatian)	ORDOVICIAN	PALEOZOIC
					38 Frankfort, N.Y. 1840			1500	6000	2000			
					37 Utica, N.Y. 1842	Trenton							
		Mohawk (N.Y. 1840)	II	II c Trenton Limestone	36 Trenton, N.Y. 1837	Ot		750	500		Mid. Ordovician (Mohawkian)		
					35 Black River, N.Y. 1842	Obr		40					
					34 Lowville, N.Y. 1838 "Birdseye"	Ot		180	100				
		Blount (Tenn.)			32 / 31 not represented					750			
		Chazy (N.Y. 1842)	II	II b Chazy Limestone	29 Valcour, N.Y. 1905	Chazy		245			Low. Ordovician		
					28 Stones River, Tenn. 1857	Stones River		250		1050			
					27 not represented								
		Beekmantown (N.Y. 1853)		II a Calciferous Sandrock	26 Bellefonte, Pa. 1891	Gbr		1900					
					25 Nittany, Pa. 1891	Gy		1680	1500	2300			
					24 Tribes Hill, N.Y. 1890			700					
		Ozark (Mo. 1891)	II Auroral		23 Chapultepec, Ala.	Knox		250					
					22 Copper Ridge, Tenn.			250					
					21 Conococheague, Pa. 1900	Gl		1750		1650			
	First Per. or Cambrian	St. Croix (Wis. 1877)			15 Elvinick [b Waterloo 1891; a Pleasant Hill 1891]	Cw		1850	1500	3000	St. Croixian	CAMBRIAN	
		Acadia (N.B. 1867)			14 Rome, Ga. 1890 "Waynesboro", 1909	Cph		300		1000	Acadian		
					13 Tomstown [c Ledger, 1907; b Marion, 1909; a Vintage, 1909]	Cwo				1800			
		Waucoba (Calif.)	I Primal Sandstone	Potsdam & Chazy Limestone	12 Harpers, Pa. 1894	Ct							
					11 Chickies, Pa. 1880	Ch		Not exposed		300	Waucoban		
						Cc				3350 1600			
PROTEROZOIC	Archean-Algonkian: Keweenawan	Keweenawan	Primal Older Slates	Huronian system	(Igneous) (Metamorphic) Pegmatites Porphyroblastic Wondelleck gn. Peters Creek schist Granite, gabbro Metamorphic Metamorphic schist Metamorphic Conglomerate beds Setters group	pg pb wk pc ug ws vol cy				1000 2000 10000 400 1000	Keweenawan	ALGONKIAN	PROTEROZOIC
	Archean-Algonkian: Animikian	Animikian											
	Archean-Algonkian: Huronian	Huronian	Primal Crystalline Schists	Archean							Huronian		
	Archean-Algonkian: Laurentian	Laurentian			Hartley gn. Franklin marble Baltimore gneiss	hgn Fg bgn						ARCHEAN	

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Fig. 30. Baltimore gneiss quarry. Northeast of Ithan, Delaware County.

Fig. 31. Cockeysville marble quarry, Bakers Station, Chester County.

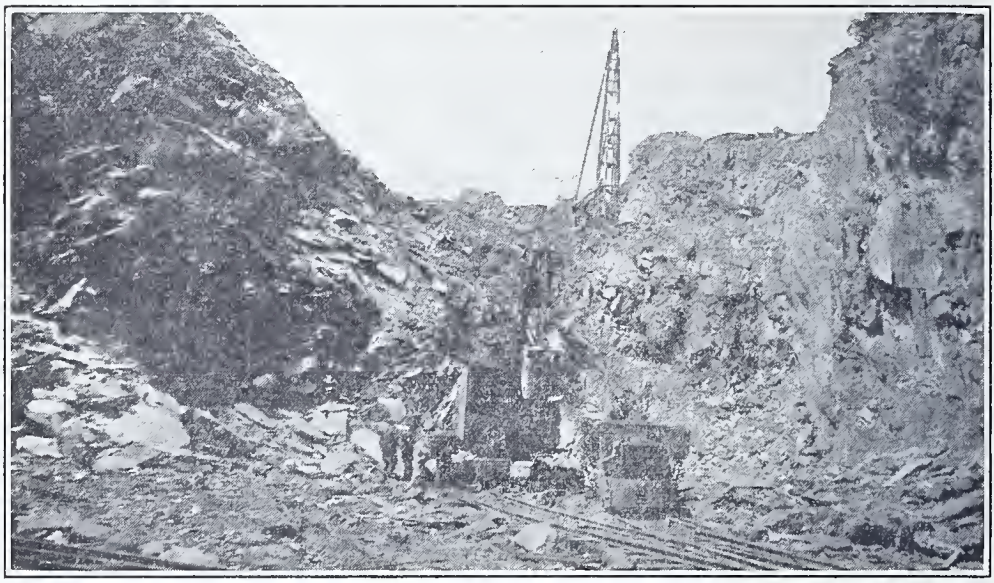


Fig. 32. Blue Mountain slate quarry. Peach Bottom slate, Delta, York County.

Fig. 33. Feldspar mine. Feldspar is white rock in picture. Elam, Delaware County.

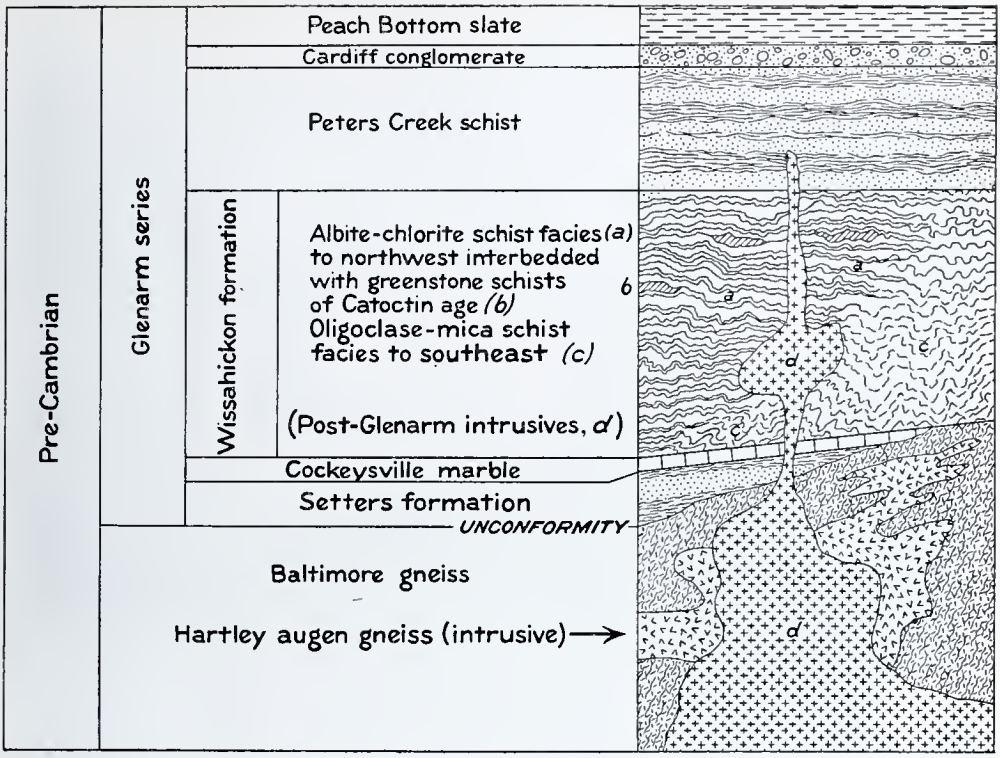


Fig. 34. Chart of pre-Cambrian rocks of Lancaster County, Pennsylvania. After Stose and Jonas.

Descriptive Table

PREHISTOREON (Pre-historic eon)

PROTEROZOIC (first life) or Pre-Cambrian

Unconformity, folding, uplift, metamorphism, and erosion of all previous sediments.

(In order, top to bottom)

Glenarm series—10,000 feet thick.

Peach Bottom slate, 1,000 feet thick, black roofing slate.

Cardiff conglomerate, several hundred feet thick; alternating layers schist, conglomerate and slate.

Intrusives, altered basalt, diabase, tuff, and rhyolite.

Peters Creek group. Quartzite, grading into chlorite-sericite schist.

Wissahickon group. Schists, alternating with quartzites in thin layers. At east has orthoclase, garnet, muscovite, biotite, etc., at west (York & Lancaster counties) less metamorphosed, with albite and chlorite predominating.

Cockeysville marble, 400 feet thick; alternating layers of calcite and dolomite marble, also called Franklin limestone.

Setters group, 1,000 feet thick; quartzite, over and underlain by mica schist and mica gneiss.

Unconformity—folding, uplift and erosion of underlying rocks.

Hartley gneiss, a metamorphosed intrusive granite.

Baltimore gneiss, a light-colored, granite-like rock, metamorphosed sediments—the oldest rock known in the State.

The oldest rocks. Pre-Cambrian time closed with the rocks of that age folded and worn down to a plain and sinking below sea level, at least in southeastern Pennsylvania. Immediately sand with some mud washed in and continued to accumulate on the sinking sea floor until in places nearly 5,000 feet of sediments accumulated. These sandy strata make two groups, the Chickies quartzite below, 1,000 to 1,600 feet thick, with the Hellam conglomerate at the base, 0 to 600 feet thick, and the Harpers group, sandstone, schist, and shale, 1,200 to 3,250 feet thick, including the Antietam sandstone at the top 150 to 500 feet thick. These rocks form mountains or hills in southeastern Pennsylvania today.

Fig. 35. Cambrian quartzite or sandstone (Chickies). Pit of Mt. Cydonia Sand Company south of Black Gap, Franklin County. Photo by R. W. Stone.

The great limestone formation. Then the crust sank deeper and changed so that the sea spread westward and many thousand feet of limestone and dolomite were laid down. This condition continued from early Cambrian to the end of Middle Ordovician time (see time scale). The rocks comprise the Tomstown group (Lower Cambrian) 1,500 to 1,750 feet thick, of dolomite with a little shale, the Waynesboro group (Middle Cambrian) 1,000 feet thick, of limestone, marble and red shale, and the Elbrook series (Upper Cambrian) of limestone and dolomite 2,000 to 3,000 feet thick.

Dolomite predominated in Lower Canadian (Ozark series) 1,000 to 2,000 feet thick, and Middle Canadian (Beekmantown series) 1,000 to 2,300 feet thick. Upper Canadian time (Chazy series), Stones River group, saw 200 to 1,000 feet of massive pure limestone laid down.

Here are 6,500 to 11,000 feet, mostly limestone or dolomite. Then slight uplift bowed these rocks up at the south and running water wore off the top of the bow, uncovering rocks down to the Harpers group. Then sinking set in again and over the eroded edge of these older rocks was laid down the Conestoga limestone 500 feet thick; also the Lowville limestone 0 to 200 feet thick, the Black River limestone

Fig. 36. Cambro-Ordovician limestone, near Union Furnace, Huntingdon County

Fig. 37. Martinsburg shale (high in lime), Martins Creek, Northampton County. Grades into limestone below.

100 to 800 feet thick, and Trenton limestone 0 to 400 feet thick, closing this great period of limestone formation. These limestones today underlie large areas in southeastern and central Pennsylvania, from the Chester Valley on the east to the Nittany Valley on the west.

The great shale belt. For a time local uplift interrupted sinking of the crust, and streams carved valleys in the exposed limestones; then came sinking accompanied by the laying down of mud 1,000 to 3,000 feet or more deep. This mud, now changed into shales and slates of the Martinsburg series (Upper Ordovician age), extends from eastern Canada to Tennessee. These shales and the Cambro-Ordovician limestones underlie and are responsible for the long, broad valley just south and east of the Kittatinny or North Mountain.

Total thickness. Here are 10,000 to 25,000 feet of rocks. This greatest thickness is deposited at no one place, for one group is thickest here and another thickest there. The early beds were confined to southeastern Pennsylvania. The later beds when originally laid down covered the whole State.

Economic value. These rocks now yield Pennsylvania over 50 million dollars worth of mineral products annually. The slates in the Martinsburg series are the basis of our slate industry. The Trenton, Lowville and Stones River limestones, in particular, supply our cement and lime industry. Here we get limestone for building, flux for iron making, silica for brick, magnesia and other substances, and most of our brown iron ores, and our lead and zinc ores.

How long did it take? From all we know it is estimated that, including times of uplift, it required about 200 million years to lay down this vast body of rocks.

Fossils. Few fossils are found in most of these rocks and, as far as found, all are invertebrates or animals without a backbone. Of most interest are the trilobites, related to the king crabs of today, but shellfish, sponges, corals and other forms, even bacteria, are found, and serve to determine the age of the rocks in which they occur. The progress of life was still confined to changes taking place among the lower forms, changes involving the appearance of one fauna after another as the preceding faunas disappeared, each fauna closely related to the last and evidently derived from it.

Descriptive Table.

HISTORIC EON

PALEOZOIC ERA, TACONIC AGE

(In order, top to bottom)

Third Period, Ordovician System.

Upper Ordovician (Hudson River or Cincinnati) series, Pulaski (Upper Martinsburg or Upper Reedsville) group. (Group 39)

Frankfort (Middle Martinsburg or Middle Reedsville) group. (Group 38)

Utica (Lower Martinsburg or Lower Reedsville) group. (Group 37)

The Upper Ordovician in Pennsylvania consists of a great thickness, 1,000—3,000 feet or more, of shale or slate, with some sandstone. "Hudson River shales" of old reports. In places this shaly mass extends down and includes the Trenton group ("Basal Martinsburg"). This series yields most of the commercial slate of Pennsylvania.

Middle Ordovician (Mohawk) series

Trenton group (Group 36). In central Pennsylvania 320 feet of thick-bedded, black limestone weathering grayish. In eastern Pennsylvania commonly represented by shale or slate with some limestone. Shaly limestone in Delaware River basin of Lower Trenton age 0-400 feet thick, "Jacksonburg," "Nazareth," "Lehigh," "Leesport," limestones, are the basis of the portland cement industry in the Lehigh Valley. (See Figure 37)

Black River group (Group 35). Represented by the upper part of the Black River (Upper Chambersburg) limestone 800 feet thick, or by the Black River (Rodman) limestone 30 feet thick in central Pennsylvania. In Lehigh region represented by Black River (Nisky) limestone 100 feet thick.

Lowville group (Group 34). "Birdseye limestone" of old reports, 200 feet or less thick. Dove-colored to dark, thick-bedded, glassy to fine-grained, pure limestone much quarried in center of State.

Lower Ordovician (Blount) series. (Not known in Pennsylvania?)

Second Period, Canadian System

Upper Canadian (Chazy) series

Stones River group. (Group 28) The middle group of the series. 180—1,050 feet thick. In Franklin county, 600 feet of massive pure limestone with black chert; 275 feet of thin-bedded, fine-grained, pure, dove-colored limestone. In central Pennsylvania, where it has been called the "Carlim" limestone, it is 180 feet thick and largely quarried for flux. At top is Stones River (Lemont) shaly limestone.
Upper and lower parts of series absent.

Middle Canadian (Beekmantown) series

Not subdivided except in central Pennsylvania. 1,000—2,300 feet thick. Impure and dolomitic limestone, heavy bedded, with chert and sandy layers. Called "Coplay" limestone in Lehigh Valley. In centre of State divided into Bellefonte dolomite (1000') at top, Axemann limestone (100') at middle, and Nittany dolomite (1000') below middle, Stonehenge limestone at base.

Lower Canadian (Ozark) series

Chepultepec Group (Group 23). Represented by Chepultepec (Larke) dolomite, 250 feet thick, thin-bedded, steely-blue dolomite.

Copper Ridge group (Group 22). Represented by Copper Ridge (Mines) dolomite, 250 feet thick, a cherty dolomite with oolite.

Brierfield—Conococheague group (Group 21). 900 to 2,000 feet thick, drab, dolomitic to pure limestone, sandy limestone, and dark blue impure dolomites. In central Pennsylvania called "Gatesburg," 1,750 feet thick, thick-bedded, steely-blue, coarsely crystalline dolomite, with interbedded quartzite layers. In Lehigh Valley called "Allentown," 1,500 feet thick, dolomite.

First Period, Cambrian System.

Upper and Middle Cambrian series

Elbrook group (or series) (Group 16-18). Thickness, 2,000 to 3,000 feet. Basal part is Middle Cambrian. Bluish-gray magnesian limestone with thin layers and nodules of chert and beds of shale. In Blair and Huntingdon counties divided into:

Elbrook (Warrior) limestone (above), thick-bedded, black limestone, 1,250 feet thick.

Elbrook (Pleasant Hill) limestone, thin-bedded, shaly limestone, 600 feet thick.

Middle Cambrian series

Rome-Waynesboro group, (Group 14-15). 1,000 feet thick, sandy, gray limestone and limy sandstone at base, dark-blue massive limestone and white marble at middle, red and purple shale at top.

Lower Cambrian series

Tomstown group. (Group 13). Southeastern Pennsylvania only.

Tomstown (Ledger) dolomite 1,000 feet thick, granular, gray to white dolomite, thin-bedded.

Tomstown (Kinzers) member 25 to 150 feet thick, impure dolomite and blue hackley shale.

Tomstown (Vintage) dolomite 500 to 600 feet thick, gray, heavy-bedded dolomite, weathers to white surface.

Harpers group (Group 12) 1,200—3,250 feet thick, southeastern Pennsylvania only. Dark-bluish shale or slate and ferruginous sandstone. Near middle is the Harpers (Montalto) quartzite, and at the top is the Harpers (Antietam) sandstone, 150-500 feet, white limy sandstone. Group is more shaly toward the south and metamorphosed into schist at the east.

Chickies group (Group 11). Southeastern Pennsylvania only. 1,000 - 1,600 feet thick. Massive-bedded, light-colored, glassy quartzite. At base Chickies (Hellam) conglomerate 0-600 feet thick, quartzite conglomerate with rounded clear and blue quartz grains. The Harpers and Chickies (?) are called Hardyston quartzite in the Delaware River areas. In the South Mountain region the Chickies group has been called the Weverton.

Unconformity.

Distribution. Cambrian limestones, groups 13-19, are part of the limestones that underlie the Chester Valley from east of Norristown to Quarryville; the broad Lancaster Valley; the York Valley, extending from east of Columbia, past York to west of Hanover; the southeast half of Kittatinny Trench from Easton to Greencastle; and Nittany Valley in central Pennsylvania. Adjoining the limestone of some of these valleys are belts of Lower Cambrian sandstone, quartzite and schist. These belts are commonly narrow but locally broaden out. These hard rocks underlie or fringe the Pigeon Hills, Hellam Hills, Welsh Mountains and other mountains of southeast Pennsylvania.

Structure. Highly folded, compressed and squeezed, locally greatly faulted. All more or less metamorphosed, the metamorphism increasing from west to east. Several times during their deposition these rocks were subjected to local folding and uplift, followed by erosion. They were folded again in late Carboniferous time.

Rocks of Middle Paleozoic Time or the Age of Fishes.

Where found. Next in order are the Silurian and Devonian rocks of Pennsylvania which range from 3,500 feet thick in Erie County to 17,000 feet in eastern Pennsylvania. These rocks underlie most of the area from Kittatinny Mountain on the southeast to Allegheny Mountain at the northwest. In the west end of the State they lie below the "coal measures," and yield oil and gas. They underlie all of northern Pennsylvania. They are especially distinguished from the rocks below by containing fish remains.

A *mountain-making sandstone.* Lower Paleozoic time closed with a slight uplift followed by erosion. As the sea bottom sank again, sand with some red mud washed in and accumulated to a depth of 500 to 2,000 feet over all that part of the ocean floor that later became central and western Pennsylvania, eastern Ohio, western New York and adjacent Canada. These strata are known as the Medina sandstone. Later part of this turned into quartzite which (upturned) today makes the backbone of most of the high, narrow mountains of central Pennsylvania.

The iron ore shales. Middle and Upper Silurian time saw 900 to 2,600 feet of shale laid down, deep red toward Delaware River. In Clinton time, shell-covered shores stretched from New York to Alabama. Then iron-bearing waters came, dissolved out the lime of the shells and left iron in its place, thus forming the Clinton red iron ore. The upper half of these shales (Salina) contains beds of salt, indicating low shores, with lagoons in which sea water evaporated. Near the top, these shales became limy (Tonoloway group) and then came real limestone, (Helderberg group) at the base of the Devonian, the two together 150 to 1,250 feet thick.

A *glass sand bed.* Then conditions changed abruptly and a layer of white or gray glass sand, the Oriskany sandstone, was laid down.

Fig. 38. Medina sandstone east side of Delaware Water Gap, showing how a massive resistant sandstone may determine the location and height of a mountain. Photo by R. W. Stone.

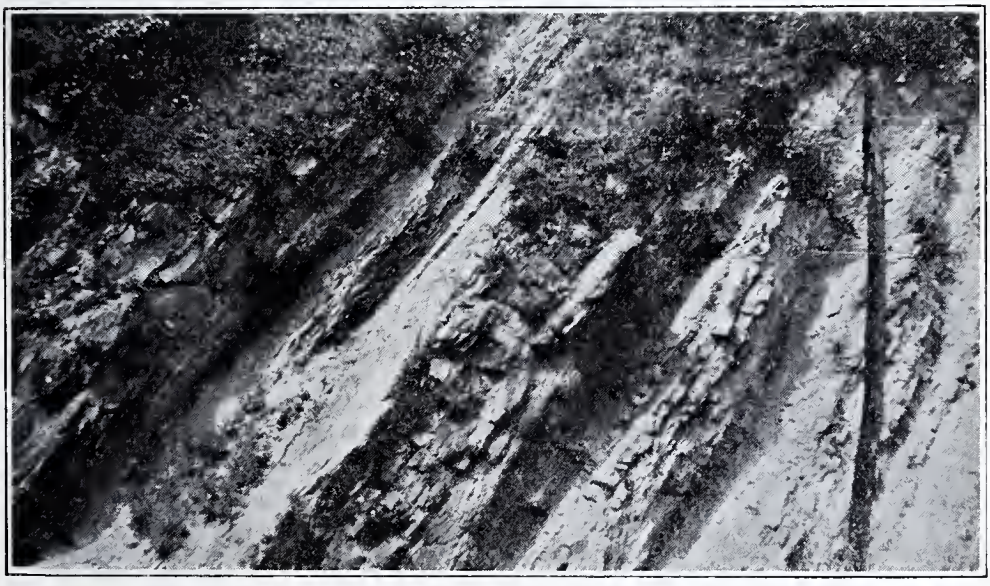


Fig. 39. Shales and sandstones of Middle Silurian age. Near Mifflin, Juniata County.

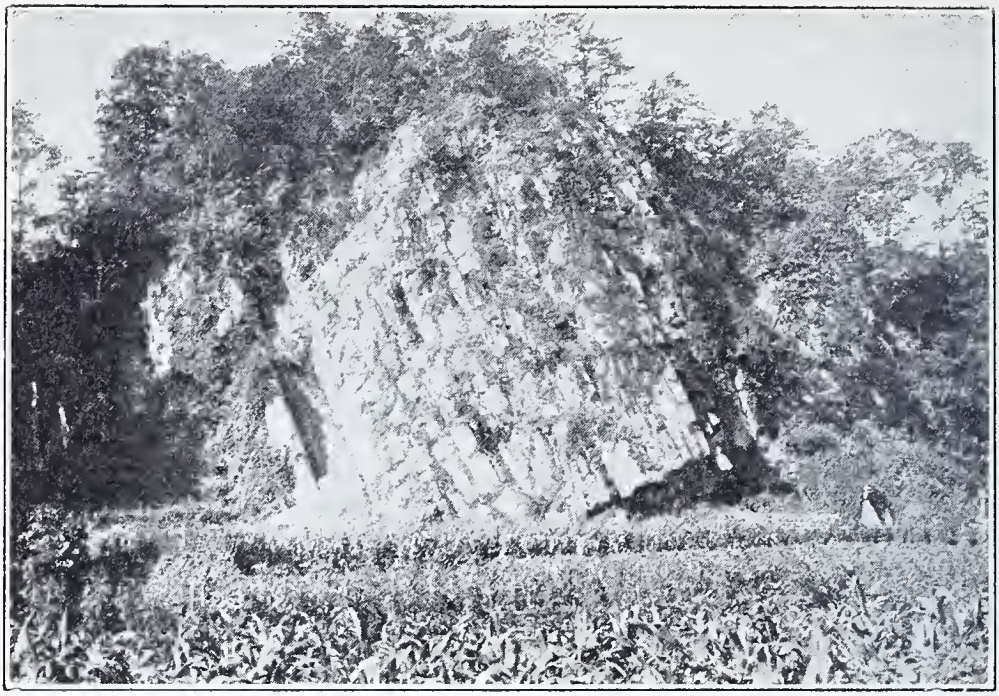


Fig. 40. Helderberg limestone north end of Tyrone, Blair County. The left side of the exposure is the Tonoloway limestone (Silurian), and the Oriskany sandstone shows through the trees at the right.

Fig. 41. Oriskany sandstone. Characteristic appearance of outcrop in lower right hand corner. Bed faces exposed in quarry in background. Mapleton, Huntingdon County. Quarried for glass sand.
Photo by R. W. Stone.

Fig. 42. Upper Devonian shales. Lewis Run Boro, McKean County.

Fig. 43. Flagstone (bluestone). Occurs in Upper Devonian. South Montrose, Susquehanna County. Photo by R. W. Stone.

Then came a time of widespread coral reefs forming another thin limestone, overlain by a thin, persistent, cherty limestone (Onondago lime stone), beginning Middle Devonian time.

A *great delta.* A delta is a fan-shaped body of mud and sand accumulated off the mouth of a river. Great rivers flowing in from the east formed such a delta in Pennsylvania in Upper or Middle Devonian time, 10,000 feet thick at the east and 3,000 feet at the west. The material in this great delta is coarse in the east and finer to the west.

This great mass has been divided from the bottom up into: the Marcellus black shale, 150 to 200 feet thick; the Hamilton gray sandstones and shales 400 to 2,000 feet thick; the Genesee black shales 0 to 150 feet thick. Then came the Portage group, typically dark shales, 1,000 to 2,000 feet thick, containing marine fossils; the Chemung group 800 to 3,300 feet thick, typically gray sandy shales and sandstones, with shore fossils; the Catskill red sandstones and shales, 7,500 feet thick at the east to 400 feet thick in western Pennsylvania. The boundaries of these groups are not clearly defined and in part they may be of the same age, but laid down at different distances from shore.

Economic value. These rocks supply quartzite (Medina) for silica brick, iron ore (Clinton), flagstones, shale for brick and tile, limestone (Helderberg) for building, sand (Oriskany) for glass and so forth, and oil and gas, in the Upper Devonian sandstones especially. Oil and gas probably originated by distillation from the remains of sea weeds and traces of fish and other sea life buried in the mud.

Fossils. Most of these rocks contain fossil shells, corals and many other remains. Of special interest are beds containing fish scales and other fish remains, almost the first trace of animals with a backbone.

Time. The Silurian is estimated to have been 40,000,000 years long and Devonian 50,000,000 years. It is estimated that during this time not less than 50,000 cubic miles of rocks were laid down in Pennsylvania.

Descriptive Table.

Fifth Period, Devonian System.

(In order, top to bottom)

Upper Devonian series

Catskill-Venango group (Group 59). At the east this group (Catskill) is red sandstone and shale 250 to 7,500 feet thick, and is thought to represent also the landward extension of at least the next two lower groups. At the west the group (Venango) consists of the following members:

59i Venango (Cussewago) limestone (1-2 feet) pure, glassy fracture.

59h Venango (Cussewago) shale (35 feet) bluish or ash-gray.

59g Venango (Cussewago) sandstone (25 feet) light brown, coarse with pebbles, disintegrates readily.

59f Venango (Riceville) shale (80 feet) fossils, drab, bluish and gray, sandy.

59e Venango (Woodcock) sandstone (20 feet) grayish, white to bluish white flagstones.

59d Venango (Saegerstown) shale (100 feet) pale blue shale and sandy flags.

59c Venango (Salamanca) sandstone (20 feet) hard gray sandstone to sandy flags.

59b Venango (Amity) shale (125 feet) blue, gray and brown shales with some red shales. Very fossiliferous.

59a Venango (Panama) sandstone (30 feet) quarry sandstone in places all pebbles. Conglomerate (= LeBoeuf sandstone = Wolf Creek conglomerate).

Chemung group (Group 58). 1,800 feet in southwestern New York where the following members occur (58f-58i outcrop in northwestern Pennsylvania):

58i Chemung (Chadokoin) member (300-500 feet) blue, sandy shale and sandstone and chocolate shale.
58h Chemung (Girard) shale (225 feet) gray, blue, and green shale.
58g Chemung (Cuba) sandstone (30-40 feet).
58f Chemung (Northeast) member (450 feet) alternating layers of gray shale and thin, hard sandstone.
58e Chemung (Shumla) sandstone (20-40 feet) discontinuous.
58d Chemung (Westfield) shale (120-165 feet) black at west, gray and sandy at east.
58c Chemung (Leona) sandstone (40-55 feet) (Bradford oil sand?)
58b Chemung (Gowanda) shale (300-500 feet) black at west, gray and sandy at east.
58a Chemung (Dunkirk) shale (100-200 feet) black shale, with some sandstone.

Portage group (Group 57). 1,000 feet thick. As developed in southwestern New York, subdivisions not yet definitely distinguished in Pennsylvania.

57i Portage (Hanover) shale (200 feet).
57h Portage (Pipe Creek) shale (30 feet).
57g Portage (Nunda) sandstone (0-200 feet).
57f Portage (Gardeau) flags and shale (350 feet).
57e Portage (Grimes) sandstone.
57d Portage (Hatch) shale and flaggy sandstone (25-0 feet).
57c Portage (Rhinestreet) black shales (2-200 feet).
57b Portage (Cashaqua) shale to flaggy sandstone at east (150 feet).
57a Portage (Middlesex) black shale (50 feet).

Genesee group (Group 56). In Pennsylvania 0-150 feet thick. Members in typical area in New York:

56e Genesee (Standish) flags and shale.
56d Genesee (West River) shales.
56c Genesee (Genundewa) limestone.
56b Genesee (typical) black shale.
56a Genesee (Tully) limestone.

Middle Devonian series.

Hamilton group (Group 55). In Pennsylvania 400-2,200 feet thick. In New York limestone and limy shales at west and sandstone and sandy shale at east. Members in New York as follows:

55d Hamilton (Moscow) shale, fossils replaced with silica.
55c Hamilton (Tichener) limestone, "Encrinal limestone."
55b Hamilton (Ludlowville) shale.
55a Hamilton (Skaneateles) shale.

Marcellus group (Group 54). In Pennsylvania 150 to 180 feet. Typically dark shale. In New York has following members:

54d Marcellus (Cardiff) shale.
54c Marcellus (Stafford) limestone.
54b Marcellus (typical) black shale.
54a Marcellus (Cherry Valley) limestone.

Onondaga group (Group 53). "Corniferous limestone" in some old reports. In Pennsylvania 250 feet and less.

53e Onondaga (Kanouse) sandstone, New Jersey.
53d Onondaga (Seneca) limestone, pure limestone in New York.
53c Onondaga ("Corniferous") limestone, persistent, beds 1-10 feet thick with many black flint nodules 1 inch to 1 foot in diameter.
53b Onondaga (typical) limestone, light gray, whitish, semi-crystalline limestone full of shells, crinoids, corals, etc.
53a Onondaga (Schoharie) grit. In New York.

Lower Devonian Series.

Oriskany group (Group 52). A gray to white quartz sandstone with a limy cement in places, elsewhere a quartz cement. (Stratigraphy not yet worked out for Pennsylvania).

52e Oriskany (Esopus) grit. "Caudi-galli grit" of old reports.
52d Oriskany (Glenerie) limestone. In New York.
52c Oriskany (typical) sandstone 20-200 feet thick. (Ridgeley sandstone).
52b Oriskany (Shriver) chert, in Pennsylvania.
52a Oriskany (Port Ewen) limestone, in New York, equals upper part of Stormsville shale of Pennsylvania.

Helderberg group (Group 51). 100-300 feet thick in Pennsylvania.

51e Helderberg (Becraft) limestone. "Upper Pentamerous," in Pennsylvania, up to 100 feet thick.

51d Helderberg (New Scotland) shales and shaly limestone, 6 to 150 feet thick in Pennsylvania. Lower Stormville shale of same age.

51c Helderberg (Kalkberg) limestone. Not in Pennsylvania, carries black flint.

51b Helderberg (Coeymans) limestone, 3 to 40 feet in Pennsylvania.

51a Helderberg (Keyser) member, 88 to 202 feet in Pennsylvania, limestone and shaly limestone.

Fourth Period, Silurian System.

Upper Silurian (Cayuga) series.

Tonoloway group (Group 49). 50 to 600 feet thick. Interbedded shaly limestone and limy shale; limestone dark, hard, thin-bedded.

Salina subseries: includes Wills Creek group of Maryland (Group 48) 450 to 600 feet thick. Calcareous shale or mud rock with thin red beds. Also

Bloomsburg group (Group 47). Deep red shales and sandstones 450 to 500 feet thick. Red color appears to spread up and down to other groups in Delaware basin.

Middle Silurian (Niagara) series

Lockport group (Group 46) "Niagara limestone" of Second Survey. The McKenzie limestones and shales of the Maryland Survey are placed here.

Rochester group (Group 45). Thin or lacking in Pennsylvania. Represented by "upper ore sandstone" of old reports, includes "Keefer sandstone" of Maryland Survey.

Clinton group (Group 44). 250 to 1,300 feet thick. Olive or greenish to red shales with layers of red and brown sandstone and one or more iron ore horizons. The Rose Hill formation of Maryland is of this age.

Lower Silurian (Medina) series.

Tuscarora group (Group 43). 100 to 1,000 feet thick. Massive-bedded sandstone, quartzite, and conglomerate. The principal mountain-making rock of central Pennsylvania. Used extensively for making silica brick.

Juniata group (Group 42). 500 to 1,600 feet thick. Shales and shaly sandstone mainly red. Lacking in eastern Pennsylvania.

Oswego group (Group 41). 75 to 1,300 feet thick. Hard gray sandstone with some conglomerate; secondary ridge maker in central Pennsylvania. Lacking in eastern Pennsylvania.

Silurian-Ordovician contact. In the Lehigh region there is evidence of some uplift (possibly folding) and erosion of the Ordovician before the laying down of the Silurian. The Silurian and Devonian stratigraphy of Pennsylvania has never been adequately worked out. A definite beginning of this study was made in 1929.

The Carboniferous Including the Coal Measures.

Where found. The Coal Measures, including the most valuable rocks in Pennsylvania, underlie nearly all of western Pennsylvania and small areas east of Allegheny Mountain (Broad Top and anthracite fields).

General description. The Carboniferous Age is divided into three periods, the Sixth, Seventh and Eighth, corresponding to the Mississippian, Pennsylvanian and Permian systems. Pennsylvanian takes its name from this State because of the importance of our Coal Measures. The Lower Carboniferous or Mississippian of Pennsylvania consists of two principal rock formations, the Pocono sandstone and shale at the base, 1,100 feet thick, and the Mauch Chunk red shale and sandstone, 0 to 2,000 feet thick, separated by a time gap of fully half a period when no rocks were laid down in this State. Then came the Coal Measures laid down during Pennsylvanian and early Permian time. The Coal Measures, 3,500 feet thick consist of sandstones, shales, clays, thin limestones and coal beds. They have been divided into the Pottsville series, at the base, 100 to 1,300 feet thick; the Allegheny group 300 feet thick;

Fig. 44. Pocono sandstone in face of Second Mountain, Dauphin County. The Pocono sandstone shares with the Tuscarora as a mountain maker, being responsible for many of the high mountains of central Pennsylvania and for most of the higher plateaus of northern Pennsylvania. Photo by Pa. Department of Highways.

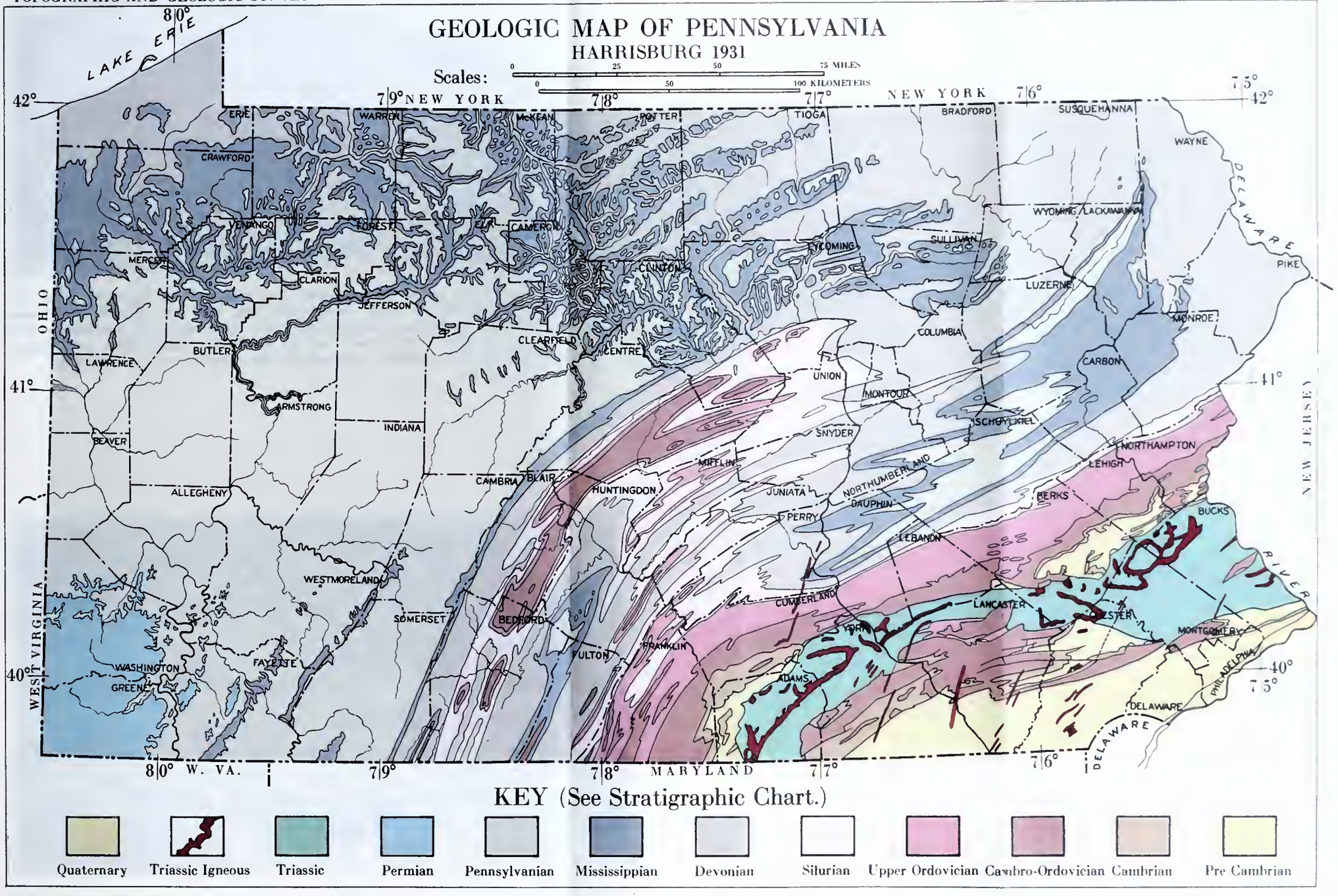
Fig. 45. Ste. Genevieve (Loyalhanna) limestone at Mineral Point, Cambria County. A characteristically sandy, cross-bedded, white limestone, traceable to Missouri and Iowa. An example of a bed, usually under 100 feet thick, having a remarkable horizontal extent of not less than 750 miles from east to west.

Fig. 46. Valley cut in Mauch Chunk shales and sandstones, between mountains formed by Pocono sandstone (on right) and Pottsville sandstone (on left), Stony Creek, Dauphin County.

the Conemaugh group 600 to 900 feet thick; the Monongahela group 300 feet thick; the Washington group 300 feet thick; and the Greene group 800 feet thick.

Pottsville uplift and erosion. During early and middle Pottsville time sinking continued in eastern Pennsylvania and southward with the laying down of sandstones, shales and coals. But in western Pennsylvania the Mauch Chunk and Pocono were lifted above sea level and largely removed by the erosion that followed. Then the whole region sank and the upper Pottsville sandstones, shales and coals were deposited. As a result the Pottsville is only 100 to 300 feet thick in western Pennsylvania while it is over 1,000 feet thick in the anthracite area and thickens southward to 7,000 feet in Alabama.

The Coal Measures. Imagine all of the Appalachian region from New York to Alabama just at sea level and covered with vast forested swamps. In the shallow water rank vegetation grows, dies, settles down and is preserved until scores of feet deep. This buried vegetation is compacted into peat and later changed to coal. Each foot of coal requires the vegetal accumulation of not less than 300 years. Then the whole area settles lower, water covers it, and 10 to 50 feet of mud or sand washes in, raising the surface to water level and starting a new swamp. This process repeated itself time after time until more than 100 beds of coal had formed in Pennsylvania and West Virginia. As each swamp accumulation was buried deeper and deeper the vegetal matter condensed, water was squeezed out, and decomposition stopped, though gaseous products continued to come off. Ultimately it became young coal or lignite. At times the downward movement was reversed and the recently deposited material was lifted above sea level and little valleys, sometimes 30 or 40 feet deep, were carved in it before it sank again.


GEOLOGIC MAP OF PENNSYLVANIA
HARRISBURG 1931
Scales:
0 25 50 75 MILES
0 50 100 KILOMETERS
LAKE ERIE
NEW YORK
OHIO
WEST VIRGINIA
W. VA.
MARYLAND
DELAWARE
NEW JERSEY
ERIE
WARREN
McKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
VENANGO
FOREST
ELK
CAMERON
WYOMING
LACKAWANNA
SULLIVAN
PIKE
MERCER
CLARION
JEFFERSON
CLINTON
LUZERNE
MONROE
BUTLER
CLEARFIELD
CENTRE
COLUMBIA
LAWRENCE
UNION
CARBON
ARMSTRONG
MONTOUR
SCHUYLKILL
INDIANA
SNYDER
BEAVER
NORTHAMPTON
MIFFLIN
LEHIGH
CAMBRIA
BLAIR
HUNTINGDON
NORTHUMBERLAND
ALLEGHENY
JUNIATA
DAUPHIN
BERKS
PERRY
BUCKS
LEBANON
WESTMORELAND
CUMBERLAND
LANCASTER
SOMERSET
BEDFORD
YORK
CHESTER
MONTGOMERY
FRANKLIN
FULTON
WASHINGTON
FAYETTE
ADAMS
GREENE
PHILADELPHIA
DELAWARE
KEY (See Stratigraphic Chart.)
Quaternary
Triassic Igneous
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Upper Ordovician
Cambro-Ordovician
Cambrian
Pre Cambrian

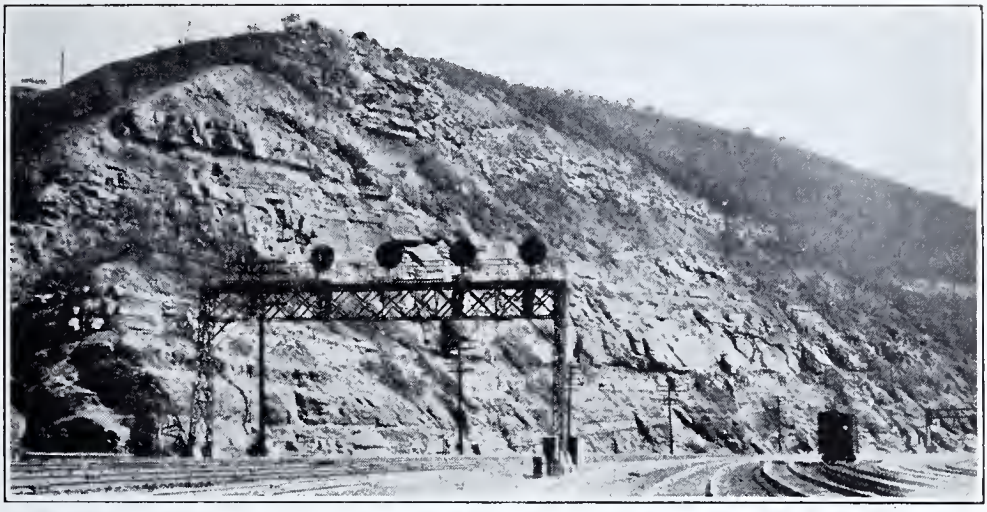


Fig. 47. General section of Coal Measures, showing alternation of shale, sandstone, limestone, coal and clay beds. East of Johnstown. The Freeport sandstone is prominent just behind the semiphore. The three white layers just below are members of the Johnstown cement bed or Upper Kittanning limestone; the Mahoning sandstone is at the top.

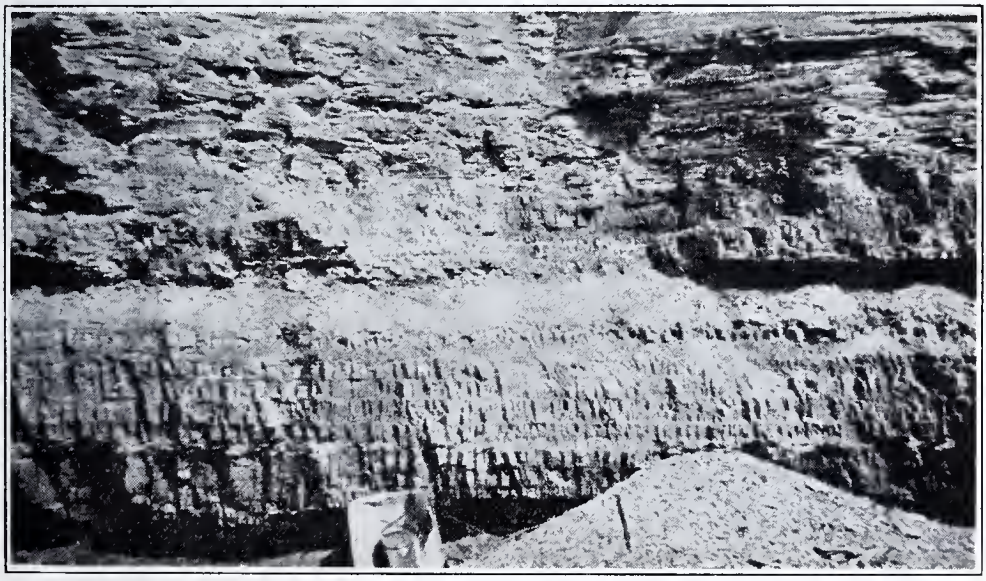


Fig. 48. Near view of coal beds and clay partings, and adjoining shale. Roof coals of Pittsburgh coal bed. (Main bed concealed below). One mile south of Trestle, Allegheny County. Photo by M. E. Johnson.

Fig. 49. Typical exposure of Coal Measures sandstone (Mahoning), near Apollo, Armstrong County.

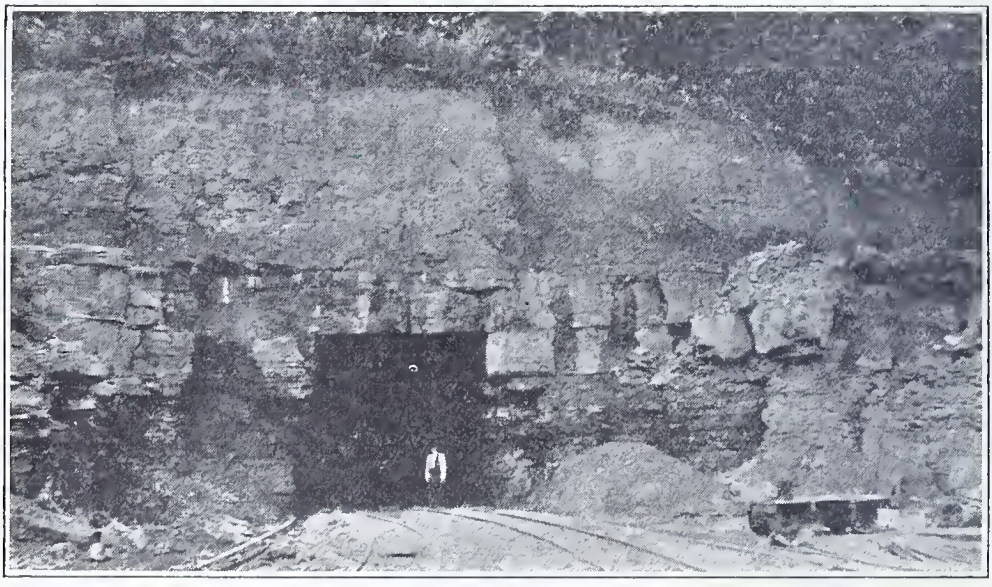


Fig. 50. Limestone in Coal Measures (the Vanport) mined for making Portland cement. Wampum, Lawrence County. Photo by R. W. Stone.

Economic value. These rocks yield Pennsylvania some years a billion dollars worth of coal, clay, limestone, sandstone and shale. In the Allegheny group occur the Freeport, Kittanning, and Clarion coals, clays and limestones. The coal beds are from 1 to 16 feet thick, averaging 2 to 4 feet thick. At the base of the Monongahela group is the great Pittsburgh coal bed 5 to 9 feet thick, the most valuable mineral deposit in the world. Other coals lie above it. The "coal measure" clays and shales supply our great clay industry, the limestones are used for flux and lime, and the sandstones for building stone. From the coal comes coke, artificial gas, and a host of by-products, as well as fuel for our great iron and other manufacturing industries.

Fossils. Plant remains of extinct species, tree ferns and other low forms, accompany most of the coal beds and the limestones usually carry animal remains. But the Carboniferous rocks also contain the remains of amphibians (frog-like animals, some as large as alligators) and the first reptiles, traces of which occur below the Pittsburgh bed. Life advanced rapidly during Carboniferous time, distinctly foreshadowing many of the higher forms to come later.

Time. The Carboniferous as a whole is estimated at about 115 million years or nearly 40 million years for each of the periods.

Descriptive Tables.

UPPER PALEOZOIC OR CARBONIFEROUS AGE

(In order, top to bottom)

Eighth Period, Permian System

The line between Permian and Pennsylvanian is not clearly indicated in Pennsylvania but has been drawn arbitrarily at the top of the Monongahela group. Only Lower Permian is thought to be represented in Pennsylvania today; whether Middle and Upper Permian rocks were deposited and later removed cannot be determined. The Permian of Pennsylvania is a continuation of the Pennsylvanian coal measures.

Here as elsewhere it is proposed to use the group name or number in connection with the names of individual beds or members in order to avoid taxing the memory and to indicate the relative position of the many named layers of rock. The Conemaugh group alone contains over 75 named beds. By putting Conemaugh before the other names the position of a bed is indicated. Thus: Conemaugh (Lonaconing) sandstone; or sandstone 78g upper. Where there are more than two beds of the same kind in any one member they may be numbered as Conemaugh (Grafton) third coal (=Federal Hill coal). In the following table B after a name signifies that the stratum forms the base of the member or coal measure.

Lower Permian (Dunkard) series 1,200 feet:

Greene group (Group 82) 700 feet.

82i Proctor 40 to 115 feet. Proctor sandstone and shale.
82h Windy Gap 50 to 140 feet. Windy Gap coal and limestone.
82g Gilmore 57 to 110 feet. Gilmore sandstone.

82f (Unnamed) 90 to 117 feet.
82e Nineveh 90 to 117 feet, Nineveh coal, sandstone, and limestone (B).
82d Hostetter 75 to 100 feet, Hostetter coal (B).
82c Fish Creek 100 feet, Fish Creek sandstone, Dunkard coal, Prosperity limestone (B).
82b Tenmile 100 to 130 feet, Tenmile or Sparta coal.
82a Donley 40 to 75 feet, Donley limestone.

Washington group (Group 81) 350 to 440 feet.
81d Upper Washington C. M., (Coal Measure) 110 to 120 feet, Upper Washington coal, limestone, Jollytown limestone and coal.
81c Middle Washington C. M. 100 to 140 feet, Middle Washington coal, Washington A. coal (B).
81b Lower Washington C. M. 60 feet, Marietta sandstone, Blacksville limestone, Lower Washington limestone, Washington coal (B).
81a (No name) 80 to 120 feet, Washington sandstone, Little Washington coal, Waynesburg B and A coals, Colvin Run limestone, Mt. Morris limestone, Waynesburg sandstone, Cassville shale (Abundant fossil leaves).

Seventh Period, Pennsylvanian System

Upper Pennsylvanian series:

Monongahela group (Group 79). 300 to 460 feet thick, "Upper Productive Coal Measures," of Second Geological Survey of Pennsylvania.
79e Waynesburg C. M. or member, 70 to 100 feet.
Waynesburg coal, shale, sandstone, clay, and limestone.
79d Uniontown C. M. 50 to 100 feet, Uniontown coal (B), Benwood (=Uniontown, Bulger, Dinsmore) limestone, shale, sandstone and clay.
79c Sewickley C. M. 50 to 100 feet, Sewickley coal (B). Fishport limestone and sandstone.
79b Redstone C. M. 30 to 80 feet, Redstone coal (B), sandstone, limestone and shale.
79a Pittsburgh C. M. 30 to 80 feet, Pittsburgh coal (B), and sandstone.

Conemaugh group (Group 78). 450 to 900 feet, "Lower Barren Coal Measures."
78i (Unnamed) C. M. 50 to 70 feet, Pittsburgh iron ores and limestones, Little Pittsburgh coal (B).
78h Connellsville C. M. 75 to 110 feet, Franklin coal (B). Franklin Rider and 2d Little Pittsburgh coal, Connellsville sandstone, Little Pittsburgh limestone.
78g Lonaconing C. M. 0 to 135 feet, Upper Clarksburg limestone (B). Lonaconing clays and sandstone, Hoffman sandstone, clays and limestones, Clarysville sandstone.
78f Morgantown C. M. 50 to 85 feet, Wellersburg coal (B). Morgantown sandstone, Clarysville coals, Lower Clarksburg limestone.
78e Barton C. M. 0 to 100 feet, Barton coal (B). upper and lower sandstone, Wellersburg limestone.
78d Grafton C. M. 50 to 135 feet, Upper and Lower Grafton sandstone, Duquesne coal, Federal Hill coal, West Milford coal, Harlem coal (B), Birmingham red bed, Barton limestone, Skelly limestone, Ames limestone, and red bed.
78c Saltsburg C. M. 60 to 100 feet, Bakerstown coal (B), Saltsburg sandstone, Jane Lew sandstone, Pittsburgh red beds, Ewing limestone, Portersville limestone.
78b Buffalo C. M. 75 to 175 feet, Brush Creek coal (B), limestone and red bed; Buffalo sandstone, Albright limestone, Cambridge limestone and red beds, Pine Creek limestone, Thomas coal, limestone, and sandstone, Meyersdale red beds.
78a Mahoning C. M. 50 to 140 feet, Upper and Lower Mahoning sandstone, Mahoning coal, limestone and red beds, Irondale limestone, Corinth sandstone, Thornton clay (base is top of Upper Freeport coal).

Allegheny group (Group 77). 300 feet thick, "Lower Productive Coal Measures."
77c Freeport C. M. 100 feet, Upper and Lower Freeport coals, limestones, and underclays; Freeport sandstone; Butler sandstone; Bolivar flint clay.
77b Kittanning C. M. 100 feet, Upper, Middle, and Lower Kittanning coals (B), Gorman coal, Bens Creek coal and others, Johnstown cement limestone, Hardman fire clay, Westernport sandstone, Ellerslie sandstone, etc.
77a Clarion C. M. 100 feet, Upper and Lower Clarion coals and sandstone, Scrubgrass coal, Brookville coal (B), Vanport ("ferriferous") limestone,

Middle Pennsylvanian (Kanawha) series. 100 feet (Pennsylvania) to 1,800 feet (West Virginia) = Upper Pottsville.

Upper and Middle Kanawha groups (Groups 76 and 75). (= Beaver River Group). In west Pennsylvania only.

76b Homewood C. M. 40 to 100 feet, Homewood sandstone.
76a Mercer C. M. 0 to 70 feet, Upper and Lower Mercer coal, Upper and Lower Mercer limestone, Mt. Savage fire clay (B).
75b Conoquenessing C. M. 80 to 175 feet. Upper and Lower Conoquenessing sandstone (B), Quakertown coal and shale.
75a Sharon C. M. 25 to 40 feet, Sharon coal and sandstone (B) (= Olean sandstone or conglomerate).

The Lykens coals in Anthracite Fields probably belong in the following groups:
Group 76
Group 75 Lykens No. 1
Group 74

Lower Pennsylvania series.

Group 73 Lykens No. 2
Group 72 Lykens Nos. 3, 4 and 5
Group 71 Lykens Valley

Sixth Period, Mississippian System

Upper Mississippian (Chester) series.

Chester (Mauch Chunk) series. 0 to 3,000 feet in Pennsylvania, but not subdivided. Lacking in northwestern Pennsylvania; 100-1,000 feet in central Pennsylvania; 2,000 to 3,000 feet near Kittatiuny Mountain. Consists of red shales and sandstones. In southwestern Pennsylvania contains the edge (20-30 feet) of Greenbrier limestone (Group 67) which thickens greatly southward and westward.

Middle Mississippian (Meremec) series.

Ste. Genevieve group (Group 66). Represented in Pennsylvania by Ste. Genevieve (Lovalhanna) limestone, 60 to 80 feet thick, sandy limestone ("siliceous limestone"); in southwestern Pennsylvania only.

St. Louis group (Group 65); not found in Pennsylvania.

Warsaw group (Group 64); not found in Pennsylvania.

Lower Mississippian (Waverly) series.

In Mississippi Valley divided into:

Keokuk group (Group 63); not found in Pennsylvania.

Burlington group (Group 62) lower half } Pocono subseries
Kinderhook group (Group 61) all } in Pennsylvania

The Pocono subseries in Pennsylvania, 700 to 1,100 feet thick consists at top of the Burgoon sandstone, 400 feet; lower half of Burlington (Big Injun sand of drillers); includes Burgoon (Shenango) member at base (shale 50 feet, sandstone 25 feet), thick-bedded sandstone with some shale. Kinderhook (Cuyahoga) group (Group 61). Subdivided as below in northwestern Pennsylvania and adjoining parts of Ohio:

61f Cuyahoga (Meadville) member, shale and limestone 65 feet.
61e Cuyahoga (Sharpsville) member, sandstone and limestone 70 feet.
61d Cuyahoga (Orangeville) shale, 75 feet; Sunbury shale in Ohio.
61c Cuyahoga (Berea) sandstone, 20 feet; Corry sandstone.
61b Cuyahoga (Bedford) shale } Ohio black shale.
61a Cuyahoga (Cleveland) shale }

The Appalachian Revolution.

Review of Paleozoic sedimentation. It is a long road that has no turning. Previous paragraphs traced the slow sinking of the earth's crust in the Appalachian region with a corresponding uplift on the east. They told of the irregular transfer of rock material from the rising land on the east into the sea-covered Appalachian region until 25,000 or more feet of sandstones, shales and limestone were spread out in central Pennsylvania, the thickness decreasing toward the west. This is roughly estimated to have required about 400 million years. As a result the earth's crust under this vast load of sediments (possibly 250,000 cubic miles), sank from 5 to 8 miles nearer the center of the earth, the lower part of it possibly reaching temperatures that softened and weakened it.

The earth's crust moves. Just what happened or why we do not know. The results make it appear that this body of rock was under vast horizontal pressure—possibly due to earth shrinkage—that accumulated until this weakened body of sediments gave way and, starting at the southeast, began to move northwestward, rising into folds as the movement gained headway. As the pressure continued these folds became higher and steeper until in some, the rock beds, formerly nearly flat, now stood straight up or were even over-turned. Imagine 20 or 30 long rugs on the floor, one on top of another, and then getting down on your knees and beginning to push one end of the pile, the other end being against a wall. The folds made in the rugs would resemble those made in the rock strata of the earth's crust.

Fig. 51. In earth movements many of the weaker beds, such as shale or thin-bedded sandstone, became tightly folded. Along Juniata River, Perry County. Photo by F. J. W. Horich.

Crushing and faulting. The folding, at first all at the east, gradually spread westward. As folds became vertical the pressure acted across the folds and not with the bedding. Some of the folds broke and one part overrode another, sometimes for several miles. In places soft beds, like the shales, simply crumpled up.

Reference should be made to Figure 3, showing beds of rock turned up on edge as seen characteristically all over central Pennsylvania; also to Figures 11 to 18, which illustrate many phases of the folding to be seen in road and railroad cuts.

In addition to the major folds there has been much close folding of the softer beds, and even crumpling, as in Figures 51 and 52.

Metamorphism at the east. At the east where the yielding was greatest, other changes took place. The round pebbles in certain conglomerates became flat, like pennies. Shales changed to slates, limestones to marbles. The water of composition of the clay minerals was driven out

and the minerals changed to feldspars, micas and so on. Many rocks changed to schists. Coal beds at the east were distilled, as though in a gas retort, and became anthracite. Farther west partial distillation made high-carbon or "smokeless" coal. Oil and gas-making materials in the rocks of eastern and central Pennsylvania were completely distilled, leaving only black shale.

The time involved. This folding and upheaval, called the Appalachian Revolution, occurred in late Carboniferous time and is believed to have proceeded so slowly that anyone living here at the time would not have realized what was going on.

The Alps of Pennsylvania. Evidently Pennsylvania changed from a great shallow sea receiving sediments to a land of vast mountain ranges. Some of these folds if restored would project five miles or more above sea level. If, however, the action required millions of years, as is prob-

Fig. 52. Crumpled limestone. Quarry near Northampton, Northampton County.

able, none of these folds ever reached full height. Instead we picture them soon eroding into a mass of mountain peaks rivaling in height and ruggedness the Alps, Andes or Himalayas.

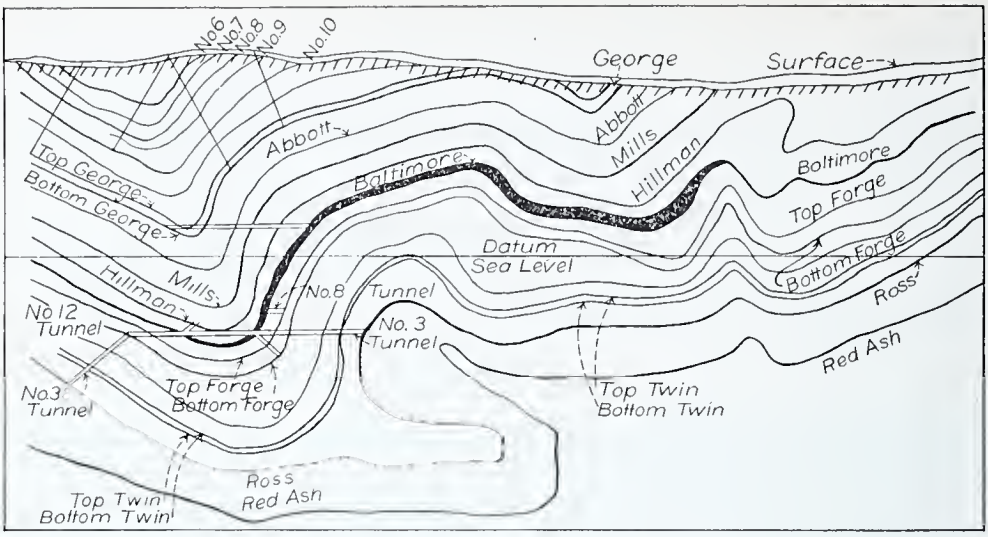
Pennsylvania shortened. Just as when you push on the end of a pile of rugs, until they take up less floor space, the Appalachian Revolution greatly shortened Pennsylvania, possibly by 100 miles, according to rough estimates. The rocks under Philadelphia may have originally underlain what is now Atlantic Ocean. (See fig. 17).

So ended Paloezoic time in Pennsylvania.

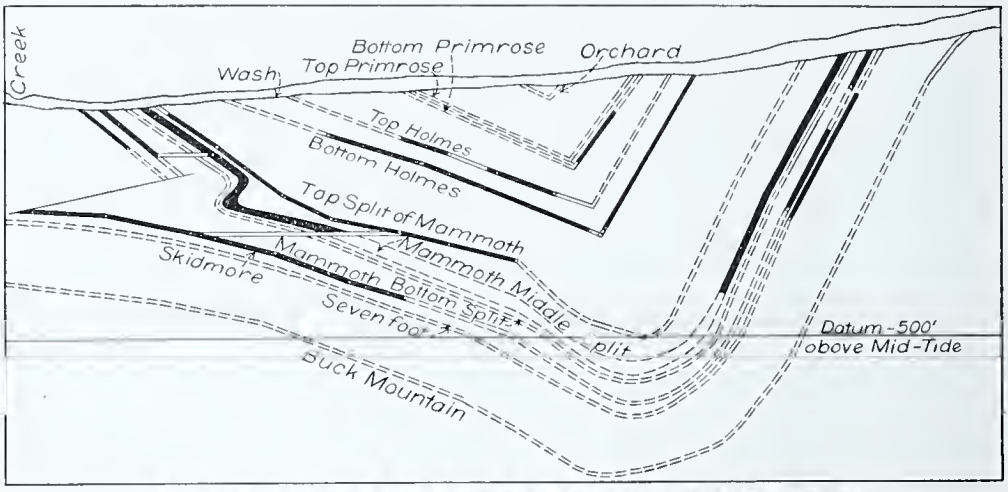
The folding to which the rocks have been subjected is well displayed in the anthracite fields where mining has followed the coal beds, (Fig. 53) or in many areas, especially along the Juniata, as in Figure 51.

Mesozoic Era. The Age of Reptiles.

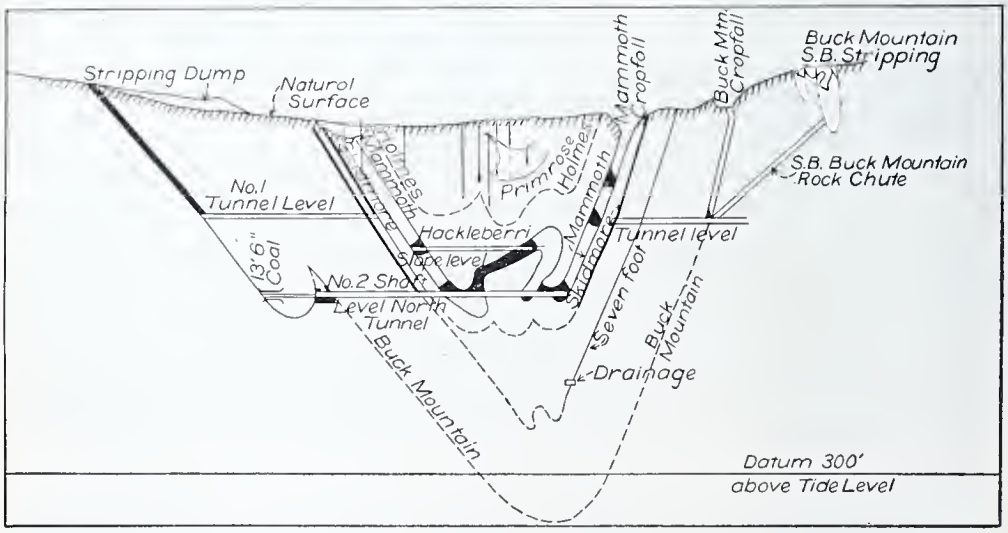
The mountains are leveled. Paleozoic time ended with Pennsylvania a land of vast uprising, breaking and crushing of the earth's



Cross-section at Auchincloss Colliery



Cross-section at Sayre Colliery, Mt. Carmel



Cross-section at Nesquehoning Tunnel

Fig. 53. Rock folds as revealed in mining anthracite. After Kemp.

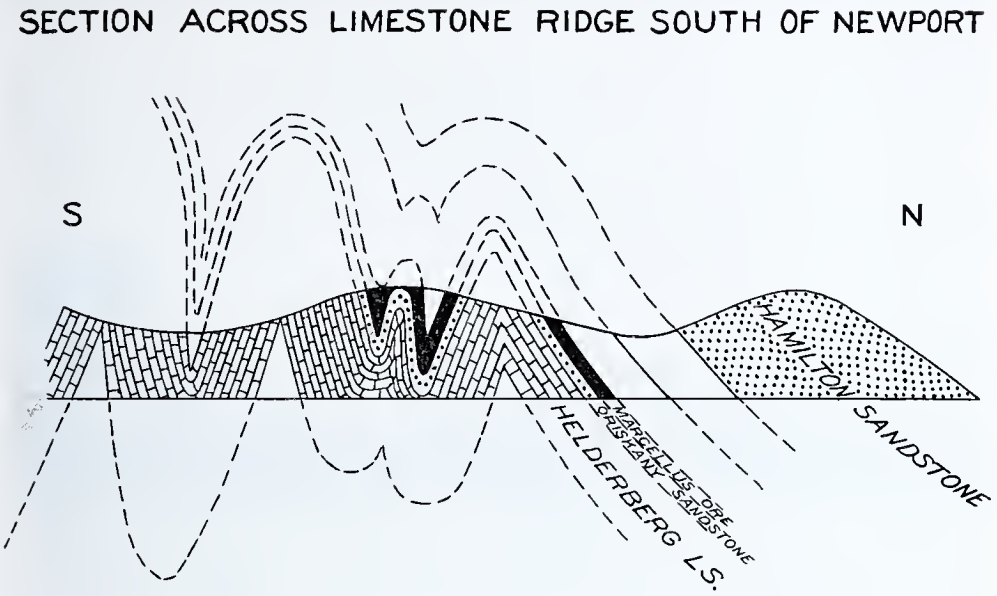


Fig. 54. Section across Limestone Ridge south of Newport, Perry County.

Fig. 55. View of the Alps, near Grindelwald, suggestive of conditions in Pennsylvania at the time of the Appalachian Revolution. Photo by G. H. Ashley.

Fig. 56. Erosion plain northeast of Gettysburg, from Pigeon Hills. View probably characteristie of appearance of Pennsylvania after the erosion here deseribed. Photo by R. W. Stone.

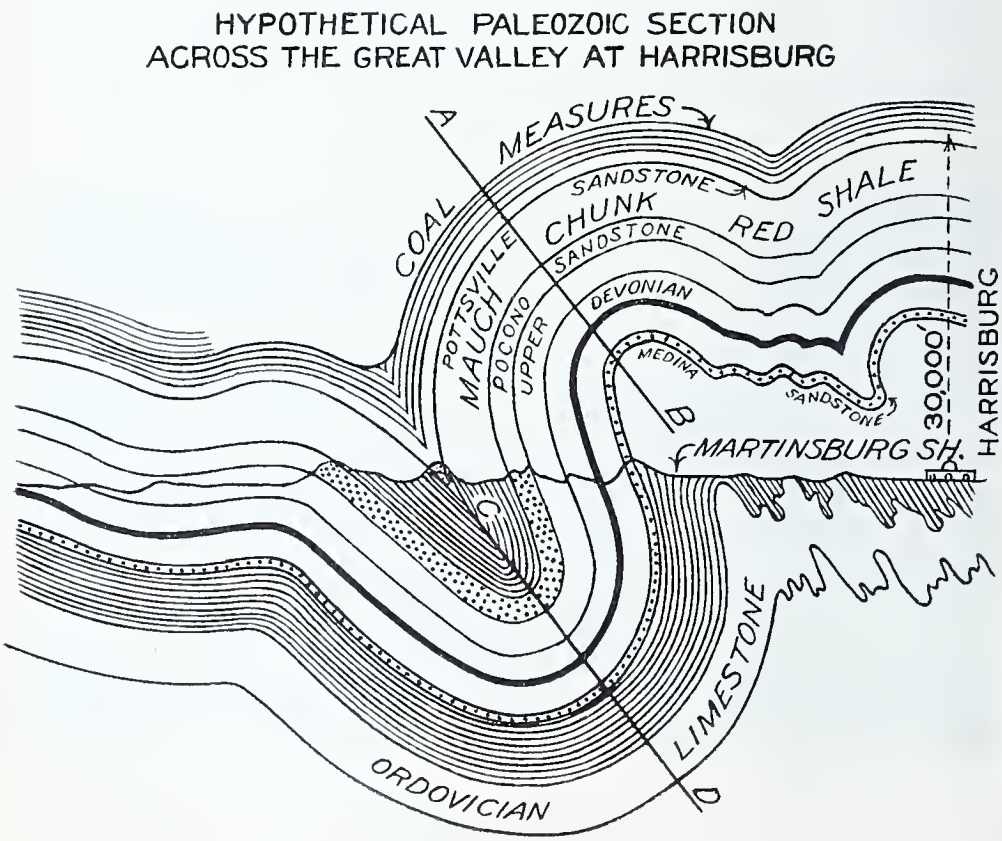


Fig. 57. Section of beds along Susquehanna River, near Harrisburg, with the eroded rocks restored will give an idea of the volume of rock removed. From the Seeond Geological Survey.

crust, with uplifted rock folds being carved into lofty mountains, the rival of any in the world today. From then on Pennsylvania remained above sea level, for the most part as it is today. Weather and running water steadily wore down this land until before the end of Mesozoic time—less than 200 million years—Pennsylvania became an almost featureless plain sloping gently from the center of the State toward the ocean on the east (for the land at the east had sunk), and toward a great gulf in the Mississippi Valley.

The birth of our rivers. On this sloping surface developed the Delaware, Susquehanna, Juniata, and other rivers of the State, or at least parts of these rivers.

This simple process of quiet land slowly being worn down by running water was interrupted by a period of violent earth action and by several periods of local sinking and flooding by the sea.

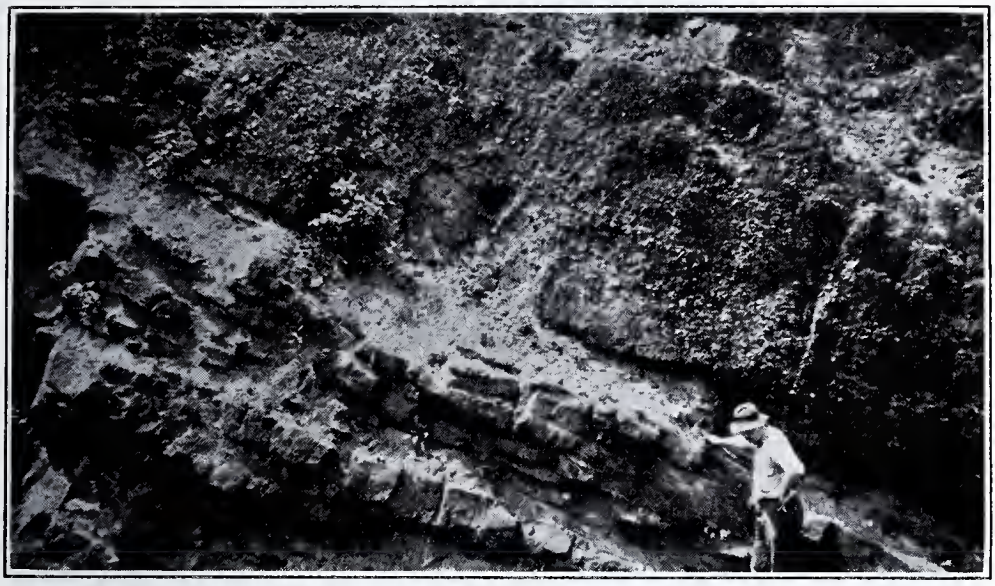


Fig. 58. Triassic red sandstones and shales; near York Haven, York County.

Crustal breaking and lava flows. In late Triassic time (9th period) great cracks rent the crust of the earth in places from the Connecticut Valley across Pennsylvania to North Carolina.

The crustal blocks on either side began to sink or rise. At the same time, as though flowing from beneath the sinking areas, vast floods of molten rock welled up through crevices, sometimes reaching the surface or spreading out between the beds of sediment that had washed in on the sinking areas. The molten rock, now cooled and hardened into "trap," today makes many of the rough hills in southeastern Pennsylvania. The red muds and sands that washed down into the sinking belts became the "Triassic red beds." They have an apparent thickness of between 20,000 and 30,000 feet.

After those strenuous times, Pennsylvania became quiet again and the slow wearing down of the land was resumed.

Fig. 59. Cliff of trap or diabase, a cooled and hardened rock that came up through the strata in molten form, showing typical fracturing. At Cornwall, Lebanon County.

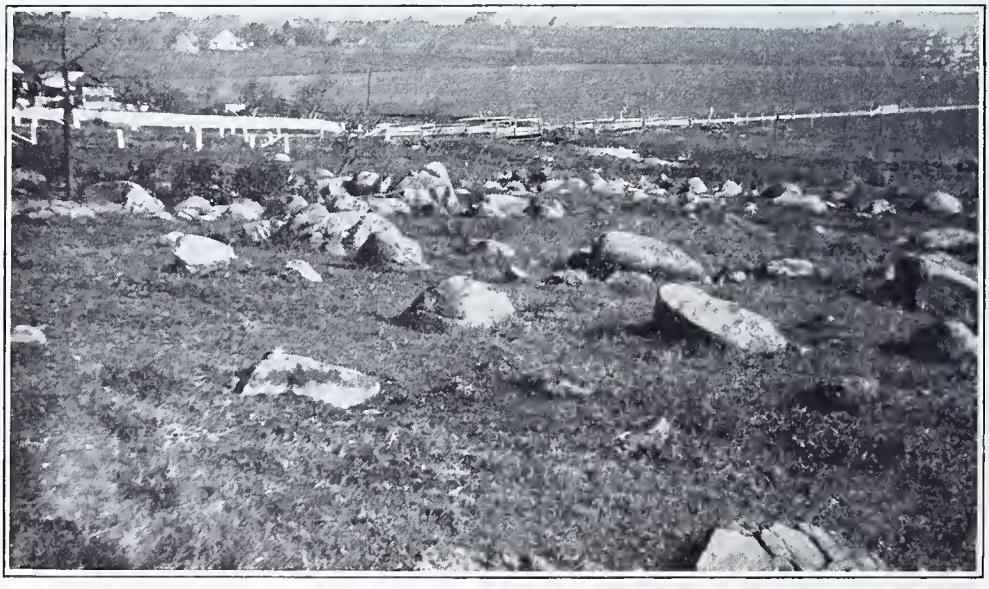


Fig. 60. Slope between Geryville and Trumbauersville, Bucks County, showing weathered trap. Often mistaken for glacial bowlders because of rounded forms taken by trap in weathering. Photo by R. W. Stone. (See also Fig. 103).

Ninth Period, Triassic System

No record of Lower Triassic.

The following table shows the sub-divisions of these rocks in four places in the State:

Upper Triassic strata (from top down)

Delaware River. (U. S. G. S. & N. J. Survey)

Stockton (2300-3100′), coarse feldspathic conglomerate, yellow micaceous sandstone, dark red sandstone, and soft red clay shale.
Lockatong (1800-3600′), hard dark-colored shales and flagstones.
Brunswick (12,000′), soft shales with local sandstone layers, dominantly red.
Total 18,000′.

Bucks and Montgomery Counties. (Lyman)

Pottstown shales (10,700′), soft red shales.
Perkasie shales (2,000′), hard, green and dark red shales.
Landsdale shales (4,700′), soft red, limy shales, with some saudstone.
Gwynedd shales (3,500′), hard, dark red aud green, partly black shales.
Norristown shales (6,100′), red shales and limy shales with thin beds or brown building stone.
Total 27,000 feet.

Dauphin and York Counties. (Bissell)

Lisbon group (10,500′), purplish, nonfeldspathic sandstone, red shale and conglomerate.
Lewisburg group (3,500′), soft red shale, with some red sandstone.
Conewago group (8,000′), alternating hard, purplish, or pinkish red sandstone and red shales.
Manchester group (7,000-8,000′), coarse grained, highly micaceous, greenish gray, relatively soft sandstone with interbedded red feldspathic sandstone and shale.
Total: 30,000 feet.

Adams County. (Stose)

Heidlersburg group (8,000′), upper part soft red shale and sandstone, lower part red shale and sandstone interbedded with hard gray to white sandstone and a little gray to black shale.
Gettysburg shale (7,500′), chiefly soft red shale and some red sandstone altered by injection of thick diabase sill to hard argillite, brownstone and porcellanite.
New Oxford group (6,900′), red shale and sandstone with many beds of harder, light-colored micaceous sandstone, arkose and conglomerate. Coarse red quartzite conglomerate locally at base.
Total 22,400 feet.

Tenth Period, Jurassic System

So far as known no rocks of this age occur in Pennsylvania nor have any yet been found and certainly recognized in New Jersey. It may therefore be judged that at this time Pennsylvania was a land area undergoing slow reduction of level. It is, of course, possible that rocks of Jurassic age were laid down in this State and in New Jersey and were completely removed before the beginning of the next period. Of this, however, there is no clear evidence known today. Some have thought that the rocks of recognized Upper Triassic age may have extended over into the Jurassic. However, Upper Triassic fossils have been found in the upper part of the Triassic sediments.

CRETACEOUS AGE

Eleventh Period, Lower Cretaceous or Comanchean System

A very few small patches of clay and gravel found in southeastern Pennsylvania are thought to belong to the Patapsco group at the top of the Lower Cretaceous system. No fossils have been found in them and the age is judged on the similarity of appearance of these clays and gravels with clays and gravels found in New Jersey, Maryland, Delaware and other States, which do contain fossils or are so associated with other rocks containing fossils as to leave no doubt of their Lower Cretaceous age. These clays and gravels are only a few feet thick and consist in the main of highly colored clays. They occur at sea level along the Delaware River and rise 200 to 400 feet above sea level within 20 miles northwest from the river.

Twelfth Period, Upper Cretaceous or Cordilleran System

Rocks of this age are not known in Pennsylvania, though as just stated, they are abundant in New Jersey and possibly, if not probably, once extended over all of eastern Pennsylvania.

The history of Mesozoic time in Pennsylvania has not yet been clearly worked out but knowledge regarding it is steadily increasing.

Fig. 61. Face of cliff near Yocumtown, York County, showing Triassic dinosaur footprint.

Fig. 62. Close up of same. Note several three-toed footprints.

Life of the Mesozoic. We have very little trace of the life of the Mesozoic in Pennsylvania. The Triassic red beds contain some plant remains and tracks of reptiles. Some of these from York County are now in the National Museum at Washington.

But other States have yielded tons and tons of the bones of reptiles great and small that swarmed the land, the sea, and even the air. Some of these huge reptiles, whose bones can be seen in the Carnegie Museum at Pittsburgh and elsewhere, were 20 feet high and nearly 100 feet long.

During this time there appeared also the first birds, curious, half-reptile birds, with teeth, and lizard-like tails, and claws on their wings. So too at this time the first mammals or hairy-skinned animals appeared. They too were reptile-like in laying eggs as does the duckbill of Australia today. Before the end of Mesozoic time modern types of trees and flowers appeared, giving the landscape somewhat the appearance it has today.

Landscaping Pennsylvania, Tertiary Time.

Pennsylvania was a nearly level plain, as uninteresting scenically as a prairie, at the close of the Mesozoic era or the age of reptiles.

Uplift and downcutting. In late Tertiary time slow uplift in central Pennsylvania increased the tilt of the land toward the sea and the speed and cutting power of the streams. At first the rivers flowed down the

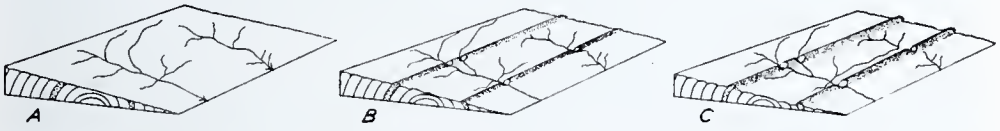


Fig. 63. Diagrams showing formation of water gaps and stream capture. A. Uplifted plain, streams starting to lower channels. B. General surface lowered except where hard layers project. C. The larger stream has captured the smaller stream, leaving a "wind gap," where the smaller stream had been cutting the lower hard sandstone.

slope of the land regardless of the rocks beneath. As they deepened their channels they cut into the underlying rocks. Where they crossed the upturned edges of hard sandstones the cutting was slow and narrow gorges were formed. In the soft rocks the streams cut rapidly and developed wide valleys.

Before long these exposed hard and soft rocks began to affect the courses of the streams. A side tributary of a main stream entering from a soft-rock valley quickly deepened and extended its valley headward along the soft rocks. So doing it often ate through the divide at its head and tapped the next transverse stream which, because of its small size, was slower in deepening its channel. Thus in time a large side tributary might capture and absorb many streams running transverse to the structure. The hard-layer gorges started by the transverse streams and abandoned became wind gaps.

Gradually these tributaries wore away all of the soft rocks down to drainage level, thus forming wide valleys between the ledges of hard rock, which remained as mountains. Long continuation of these processes produced the Pennsylvania of today: 1. Plateaus where the rocks are flat, with narrow, steepsided valleys; and flat-topped mountains where the rocks are folded (the tops are remnants of the old Meso-

Fig. 64. Scene in Jefferson County where absence of any single resistant layer has allowed much greater reduction of upland and yields a larger area of tillable land. The general level (peneplain) character of the divide forming the horizon is evident. Compare with Fig. 26. The difference is due to differences in the hardness of the rocks. Photo from Highway Department of Pennsylvania.

zoie plain); 2. Water gaps where the larger streams have cut down through the hard upturned rocks and wind gaps where gaps were started but abandoned; 3. Broad valleys following the broad belts of soft rock and narrow mountains where the much thinner hard strata are upturned. Some modifying features are described in the next chapter.

Life of the Tertiary. A land area, where everything is washing away toward the sea, is an unfavorable place for preserving organic remains. So our knowledge of Tertiary life comes from other areas where water-laid deposits occur. These show first the disappearance of most of the great orders of reptiles, leaving no descendents. Then the mammals or hairy-skinned animals seemed to have taken heart and in a short time pouched forms, like the kangaroo, followed the egg-laying mammals. Australia was cut off from the other continents at this time and life there stood still. Then began to appear the more familiar types of today, though all of the forms are now extinct. The first members of most the groups were very small and primitive, but slowly developed into larger and more specialized types. Some became elephantine before they passed out. We can trace the development of

Fig. 65. View from Reservoir Park, Harrisburg, toward water gaps of the Susquehanna. The mountain tops represent an old plain of erosio (Schooley or Kittatinny peneplain). The foreground is a later plane of erosion cut in softer rocks (Harrisburg peneplain). The water gaps were cut by the river which was formerly flowing in its present position but on top of the higher plane of erosion. The lower plane is about 200 feet above the river and is already being cut down to a new plane at river level.

many of our common animals, such as the dog, horse, camel and elephant from small, primitive types to their present form. By the end of Tertiary time the plants and animals were very similar to those of today.

Time and mountains. Tertiary age is estimated as about 60 million years long. During this time all of the high mountains of the earth today were uplifted, the Alps, Andes, Sierras, Himalayas, and others.

Quaternary Time—The Age of Ice and Man.

Ice Age. Beginning about a million years ago, so it is estimated, climatic and other conditions favored the accumulation of thousands of feet of ice west of Hudson Bay, in Labrador, and in other northern areas. As the thickness increased the ice flowed away—as a pile of tar spreads out under a hot sun—scraping up the loose soil and movable surface rock, which it shoved and carried along.

Fig. 66. Glacial till, top of Pocono Plateau near Tobyhanna. Elevation nearly 2,000 feet above sea level.

Effect of glaciers. Three primary effects of the glacier were erosion, transportation and deposition The ice cleaned off, planed down and scratched (by boulders frozen in the bottom of the ice) the rock over which it passed. Rocks and soil were carried by the ice, sometimes hundreds of miles from their source. Part of the material carried forward was dumped into valleys; part was piled up as a treminal moraine where the ice front stopped; and part of the load was dropped and spread over the whole landscape as the ice melted and the glacier retreated.

Many glacial advances. The Ice Age included at least four advances of the ice sheet, separated by long inter-glacial periods when the ice retreated northward. The time between advances is estimated by the amount of erosion that took place. For example, the Ohio River formerly flowed north through Beaver Valley to Lake Erie. An early

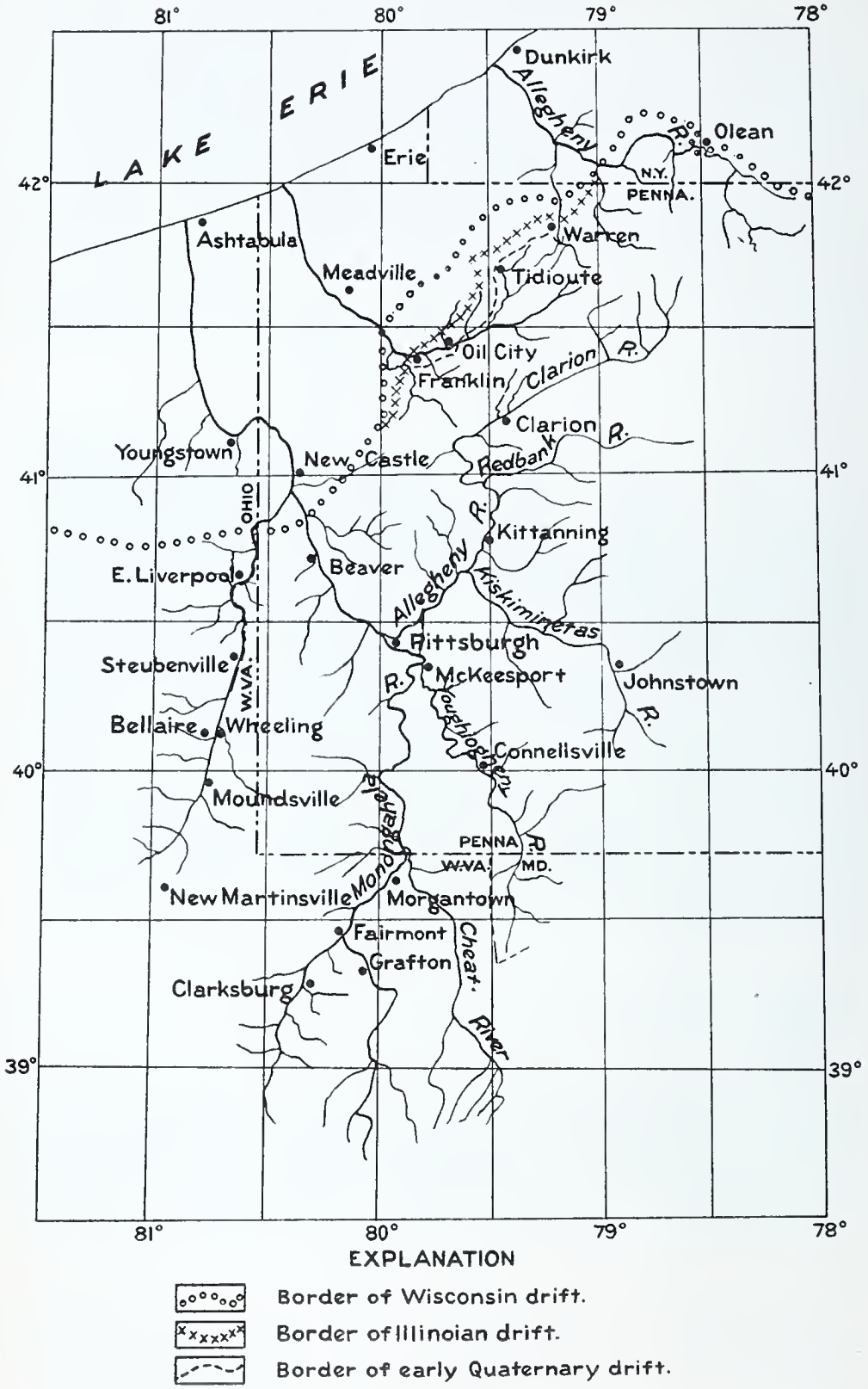


Fig. 67. Sketch showing pre-glacial drainage of western Pennsylvania. After Leverett.

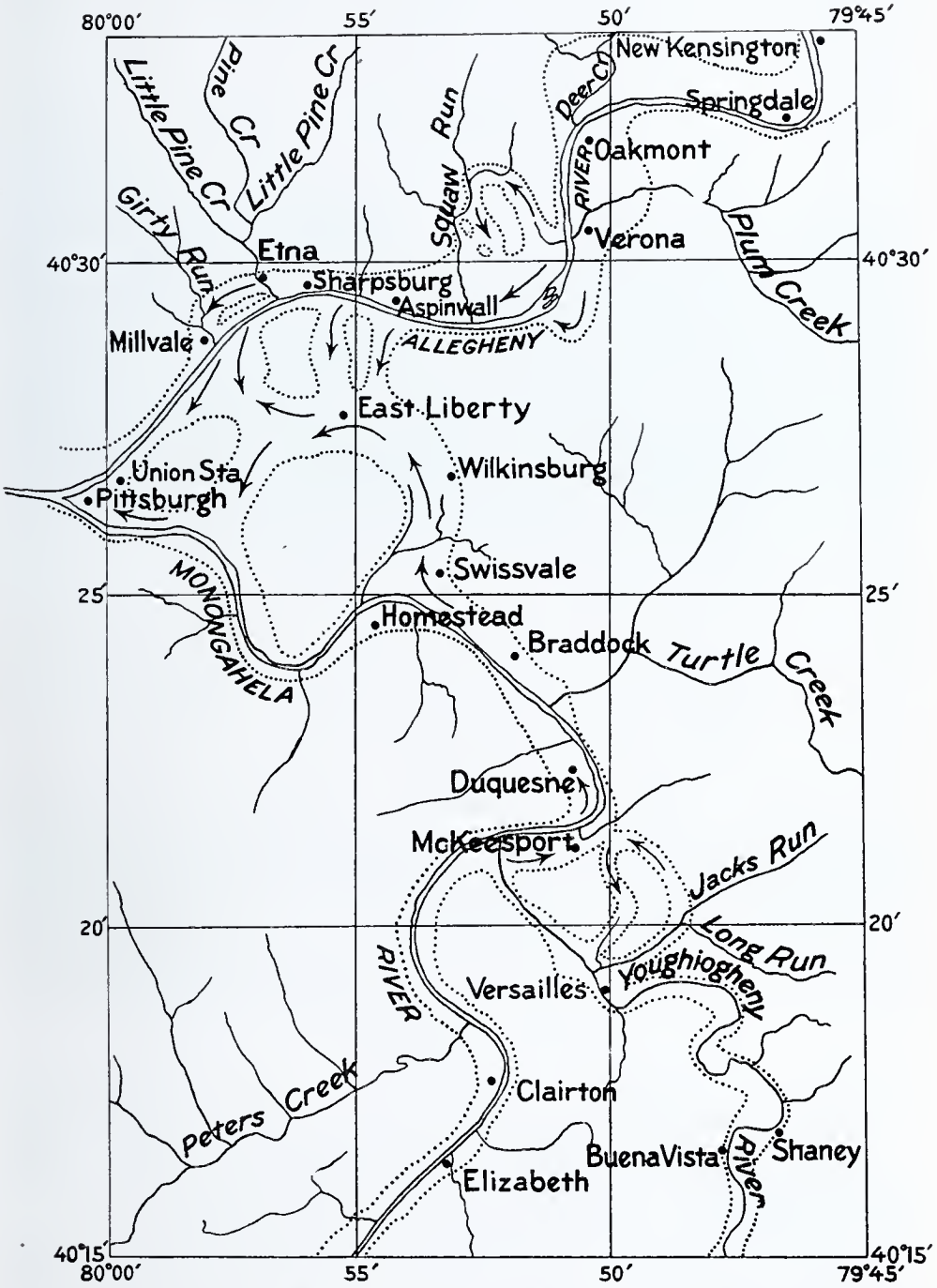


Fig. 68. Sketch showing pre-glacial river channels 200-300 feet above present rivers. Old channel shown by dotted lines. After Johnson and Leverett.

ice advance closed that outlet and turned the river southwest as now. Before the change the bed of the Ohio was 900 feet above sea level at Pittsburgh. River gravels at Carnegie Hall, Pittsburgh, show that it is in an old channel of the Monongahela. Between the first and last advances of the ice the Allegheny and Ohio had deepened their valleys to less than 700 feet above tide.

Effects in Pennsylvania. Ice advancing from these two Canadian centers swept over northeastern and northwestern Pennsylvania probably two or three times, planing off and scratching the rocks, filling up valleys, leaving one prominent terminal moraine, and in retreat spreading an irregular mantle of clay, sand and boulders, or glacial till.

After effects. Water collected in undrained hollows in this irregular mantle formed the lakes of northeast and northwest Pennsylvania. Many valleys were so completely filled that after the ice retreated the streams found new outlets, often over a rocky shoulder of the old valley, producing water falls and new post-glacial gorges below. The cutting of these post-glacial gorges gave additional opportunity to measure the time. These lakes, waterfalls and gorges add greatly to the scenic beauty of the northern corners of the State.

Life of the time. Each ice advance drove southward the polar animals of that day, and each retreat readmitted the temperate climate animals and plants. Each ice advance appears to have extinguished certain species. Deposits laid down in North America between the first and second glacial stages contain many species of gigantic, sloth-like animals, many horses, camels, elephants, mastodons, saber-toothed tigers and other animals. The camels and horses and some others disappeared before the next advance. Others lived on but became extinct before historic time.

Man comes. Finally man appeared. His bones and implements mingled with the bones of extinct animals are found in caves and in unconsolidated sediments in Europe and America. The story of early man fills many books. Excavations are revealing that man almost certainly lived in Europe and probably in America before the last ice advance and evidence is slowly accumulating that points to man's having lived far back, perhaps in the very beginning of the ice age.

Review and Summary.

If we have truly learned the story told by the rocks of Pennsylvania and elsewhere, we will have gotten three great ideas:

1. *The geologic drama of Pennsylvania.* First, instead of the hills and valleys being "eternal," they are only the present momentary scene in a great drama in which time and again the sea advanced over Pennsylvania and thousands of feet of rock material were laid down, and time and again the sea bottom rose to the surface and the sea retreated. In other scenes the earth's crust was folded and crushed: or broken along vertical cracks or floods of molten rock welled up from beneath. In some scenes Pennsylvania appears as a land of vast mountains, as high and rugged as any in the world today. In others the State lay quiet, slowly wearing away and washing to the sea. Then came uplift and the streams carved valleys out of the

Fig. 69. Valley cut since middle glacial time, in old channel of Monongahela River which previously had been running at the upland level with the bridge. From bridge in Schenley Park, Pittsburgh.

Fig. 70. Conneaut Lake, Crawford County, typical of the many lakes that formed following the retreat of the glacier. Photo by R. W. Stone.

softer rocks, leaving the hard and resistant rocks standing up as mountains. During the Ice Age great glaciers pushed their way into the northern corners of the State, completely changing the landscape; and further uplifts made the streams cut the present narrow, lower valleys in the former wide valleys.

What of the future? History may repeat itself. Pennsylvania may again wear down to sea level with tide-water rivers floating ocean vessels. It may sink below sea level and again be buried under thousands of feet of sediments. It may again be crushed and folded into lofty mountains.

2. *Time works wonders.* The second great idea to be gotten from the rocks is that of the immensity of time. The same forces that produced all of these changes are as active and as great today as ever. We do not realize their magnitude because they act so slowly. Streams carrying off sand and mud will in time completely remove the highest mountains; and the sea, spreading imperceptibly over the land, though only a few feet in a century, will in time flood half a continent. Measurements in streams indicate that it takes from 4,000 to 10,000 years to reduce the land surface one foot or to lay down one foot of widespread sediments. At that rate 100 million to 250 million years were required to deposit the 25,000 feet of Paleozoic rocks in Pennsylvania. Yet these rocks represent only a small part of geologic time.

3. *Life progress.* The third great idea the rocks show is the slow progress of life. The oldest rocks contain fossils of only the lowest forms of life. Little by little, as we come up through the succession of strata, higher and higher forms of life appear. Most of them last but a short time and are replaced by others; until, in the last minute of geologic time, man himself appears. Not only was there this progress from age to age at the top of the unfolding life from the lowest forms to man, but equally great transformations were going on in an endless number of families. Just as human races have risen, reached greatness then faded out—Egyptians, Babylonians, Persians, Indians, Greeks —so all through the story countless animal and plant families rose, grew to importance, then faded into extinction.

Chance or purpose. The question is often asked, "Was this drama recorded in the rocks the story of chance or were there plan and purpose behind it?" Today most geologists and other scientists believe that a plan and a purpose underlie this story and that in deciphering it men have been trying to retrace the footsteps of the Creator. But such a plan or purpose must affect the present and future as well as the past. Does not this thought challenge every boy and girl to so live that they shall contribute something to the progress of life; to making life stronger and richer; to look on themselves as human stepping stones to a higher race?

MINERAL RESOURCES

Introduction.

The preceding pages have described the laying down of the rocks and their contained beds of coal, clay, and iron, and the deposits of oil and gas that have today become the source of the State's great mineral industry. It is well to keep this geologic history clearly in mind, for many people imagine that our coal, oil and gas, iron, and the many kinds of rocks have always been here from the beginning. The fact that they are here as the result of geological processes acting through the long ages does not make them any less valuable nor their presence any the less wonderful. Indeed to some of us their coming here in the way they did seems much more wonderful than as though they were here at the beginning. In preparing these chapters frequent reference has been made to Report No. 9, The Minerals of Pennsylvania, by Amos P. Brown and Frederick Ehrenfeld, issued by the Pennsylvania Topographic and Geologic Survey Commission, and to U. S. Geological Survey Bulletin 585, Useful Minerals in the United States, by Samuel Sanford and Ralph W. Stone.

In the following sections are given several maps showing the location of the several mineral deposits with a very brief outline of their location, mode of occurrence, value, and production. The production figures[1] for 1923 are used rather more than those of later years, partly because for some of the details the figures for that year are the latest available, and partly because it is believed that those figures are more characteristic of what this State has been producing than the figures for more recent years when the coal industry of Pennsylvania in particular has been much upset by unfavorable conditions.

[1] Mineral resources statistical data given here are from Mineral Resources of the United States, published by the U. S. Geological Survey and since 1925 by the U. S. Bureau of Mines.

MINERAL PRODUCTION OF PENNSYLVANIA IN 1923 AND 1924.

Product	1923		1924	
	Quantity	Value	Quantity	Value
Briquets, fuel, short tons	194,973	[1]$1,160,254	93,447	[1]$543,399
Cement, barrels	[2]38,610,852	[2]69,792,343	[2]40,208,860	[2]69,693,517
Clay products		[3]58,529,481		[3]52,167,366
Clay, raw, short tons	517,392	[1]1,626,882	661,918	[1]1,942,708
Coal:				
Anthracite, short tons	93,339,009	506,786,768	87,926,862	477,230,852
Bituminous, short tons	171,879,913	472,217,000	130,633,773	295,164,000
Coke, short tons	25,624,286	[1]138,444,191	16,927,437	[1]72,568,096
Copper, pounds	1,703,480	250,411	1,114,694	146,025
Feldspar (crude), long tons	2,069	6,355	1,481	4,763
Ferroalloys, long tons	317,470	[1]28,515,265	260,623	[1]24,618,060
Gems and precious stones		[4]		[5]
Gold, troy ounces	157	3,246	214	4,424
Iron ore:				
Sold to furnaces, long tons	988,586	2,264,485	807,411	1,881,122
Sold for paint, long tons	3,516	[6]	3,005	[6]
Iron, pig, long tons	13,898,624	347,679,274	10,962,288	237,052,035
Lime, short tons	772,839	6,372,732	700,380	5,634,806
Mineral paints, zinc and lead pigments short tons	[1, 6]	[1, 6]	[1, 6]	[1, 6]
Mineral waters, gallons sold	807,522	84,945	[5]	[5]
Natural gas, M cubic feet	112,562,000	45,873,000	105,863,000	45,546,000
Natural gas gasoline, gallons	19,132,000	2,560,000	19,254,000	2,266,000
Peat, short tons	[6]	[6]	[6]	[6]
Petroleum, barrels	7,609,000	25,320,000	7,486,000	27,025,000
Potash (K_2O), short tons	[6]	[6]	[6]	[6]
Sand and gravel, short tons	9,221,292	9,944,019	11,315,209	10,927,752
Sand and sandstone (finely ground), short tons	[7]	[7]	[6]	[6]
Sand-lime brick, thousand	[3, 6]	[3, 6]	[3, 6]	[3, 6]
Silica (quartz), short tons			[6]	[6]
Silver, troy ounces	3,005	2,464	2,810	1,883
Slate		5,587,670		5,157,868
Stone, short tons	[8]15,679,170	18,997,295	[8]14,559,490	[8]17,966,836
Sulphuric acid (60° Baume),[9] short tons	[1, 3, 6]	[1, 3, 6]	118,452	[1]1,072,000
Tale, short tons	[6]	[6]	[6]	[6]
Tripoli (rottenstone), short tons	[6]	[6]	[6]	[6]
Miscellaneous [10], short tons		14,544,467		12,891,425
Total value, eliminating duplications		$1,225,036,404		$1,011,630,879

[1] Value not included in total value for State.
[2] Exclusive of natural cement, value for which is included under "Miscellaneous."
[3] Figures obtained through cooperation with Bureau of the Census.
[4] Figures by States not available for 1923.
[5] No canvass for 1924.
[6] Value included under "Miscellaneous."
[7] Included under "Sand and gravel."
[8] Exclusive of serpentine, value for which is included under "Miscellaneous."
[9] From zinc smelting.
[10] Includes minerals indicated by "2", "6" and "8" above.

FUELS

Kinds: Coal, oil, natural gas, oil shales, natural-gas gasoline.

COAL[1]

Coal is a rock, lying in beds in the earth, derived by the partial decomposition of masses of vegetable matter. Chemically it consists principally of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and some other substances. By heating it may be broken up into moisture, combustible volatile matter (gas), fixed or free (?) carbon, and ash.

[1] See Bulletin M6, List of Publications.

PENNSYLVANIA'S RANK AMONG THE STATES IN VALUE OF LEADING MINERAL PRODUCTS

1927

(FIGURES IN THOUSANDS OF DOLLARS)

THE TWENTY FIVE LEADING MINERAL PRODUCTS (In Order)	UNITED STATES	FIRST	SECOND	THIRD	OTHER
COAL	1,450,599	693,655	W.Va. 249,730	Ky. 119,249	
BITUMINOUS	1,029,657	273,714	W.Va. 249,730	Ky. 119,249	
ANTHRACITE	420,941	420,941			
PETROLEUM	1,172,830	OKla. 347,100	Texas 249,800	Calif. 241,500	5th 32,900
IRON, PIG	646,226	212,179	Ohio 150,125	Ill. 66,442	
IRON ORE	151,125	Minn. 87,935	Mich. 37,135	Ala. 12,973	6th 2,559
CLAY PRODUCTS	403,363	Ohio 92,363	50,909	N.J. 43,073	
CLAY SOLD	13,697	2,403	Mo. 1,693	Ga. 1,537	
NATURAL GAS	317,930	W.Va. 67,994	Calif. 50,946	49,135	
CEMENT	281,735	66,711	Calif. 26,623	Mich. 20,838	
COKE	262,320	67,170	Ind. 37,152	N.Y. 24,125	
COPPER	220,609	Ariz. 89,366	Utah. 33,658	Mont. 29,277	12th 227
STONE	198,647	Ind. 22,664	18,999	Ohio. 16,769	
NATURAL GASOLINE	118,688	Calif. 52,436	OKla. 29,114	Texas 18,347	10th 1,648
SAND	112,271	N.Y. 12,157	12,040	Ill. 9,166	
LEAD	84,208	Mo. 25,043	Idaho 21,838	Utah 19,061	NONE
ZINC	73,851	OKla. 40,885	Mont. 10,269		
FERRO-ALLOYS	55,163		N.Y.	Ohio	No figures
GOLD	45,418	Calif. 11,679	S.Da. 6,670	Alaska 5,918	16th 6.2
GYPSUM	42,174	N.Y. 14,889	Iowa 6,713	Ohio 5,041	NONE
LIME	38,638	Ohio 9,497	6,105	Mass. 2,325	
SULPHUR	38,300	Texas 38,000	La.		NONE
SILVER	34,266	Utah 10,973	Mont. 6,696	Idaho 5,062	18th 1.1
ZINC & LEAD PIGM.	25,275		Ohio	Ill.	No figures
SALT	24,817	Mich. 7,551	N.Y. 6,121	Ohio 3,130	NONE
SLATE	11,380	4,769	Vt. 4,108	N.Y. 812	

Fig. 71

PENNSYLVANIA'S SHARE OF NATIONAL MINERAL PRODUCTION

(VALUE IN MILLIONS OF DOLLARS)

		1914	1919	1923	1927
TOTAL	U.S.	2.433	4.595	5.986	5,529
	PA.	452 18%	918 20%	1.223 20%	936 16%
COAL	U.S.	681	1.525	2.021	1.450
	PA.	347 50%	730 47%	979 48%	693 47%
CEMENT	U.S.	80	147	259	281
	PA.	20 26%	43 29%	69 26%	66 23%
CLAY PROD.	U.S.	164	275	424	403
	PA.	21 13%	39 14%	58 13%	50 12%
NATURAL GAS	U.S.	94	160	240	317
	PA.	20 21%	31 19%	45 19%	49 15%
PETROLEUM	U.S.	214	760	978	1.172
	PA.	15 7%	33 4%	25 2%	29 2%
STONE	U.S.	77	96	159	198
	PA.	8 10%	16 17%	18 11%	18 9%
SAND & GRAVEL	U.S.	22	45	90	115
	PA.	2 13%	5 12%	9 10%	12 10%
SLATE	U.S.	5	6	12	11
	PA.	3 63%	2 47%	5 46%	4 41%

Fig. 72

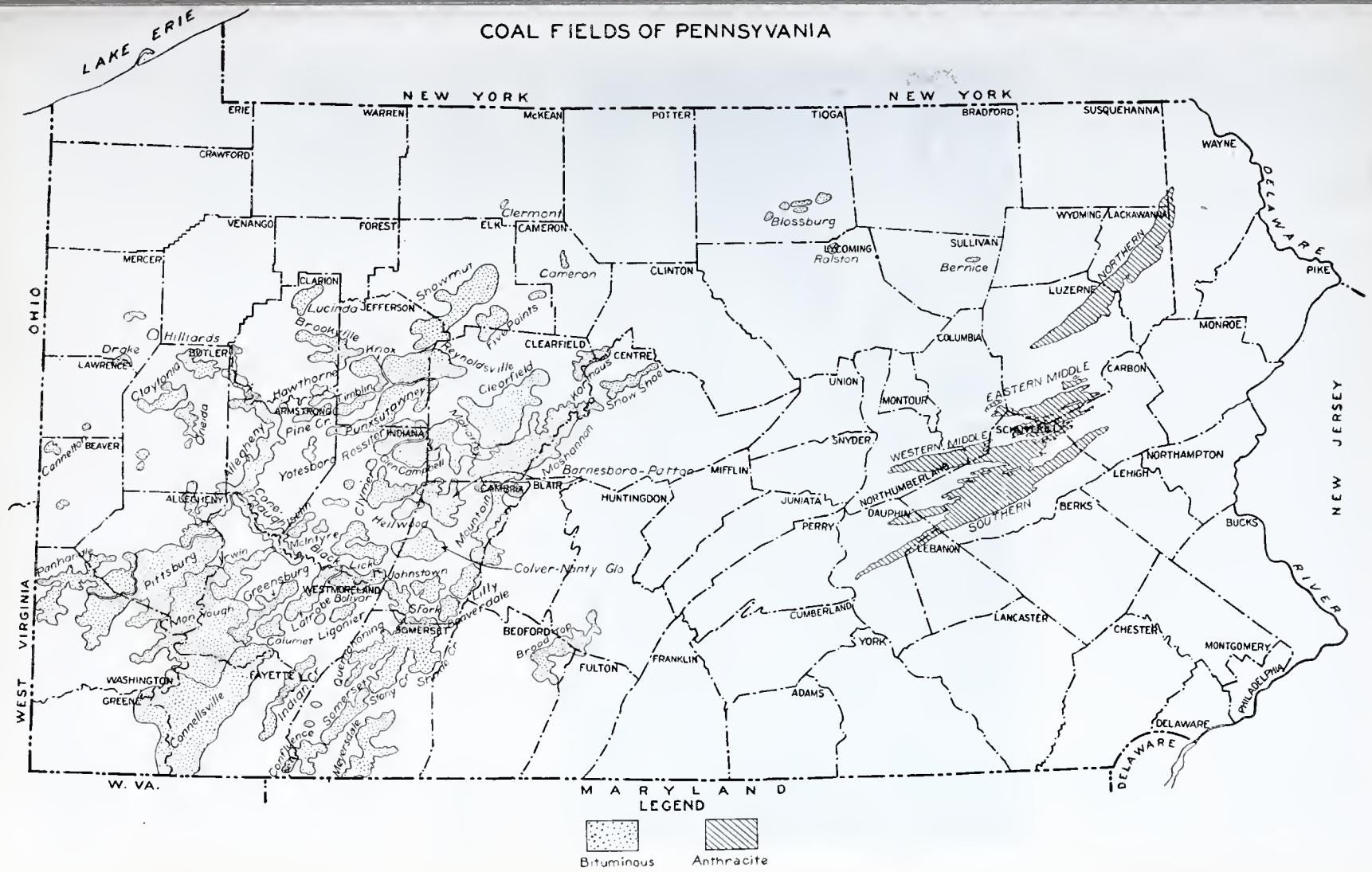


Fig. 73. Map of the producing coal fields of Pennsylvania.

Kinds. Anthracite, bituminous. Anthracite has long been divided into "hard" and "soft" or semi-anthracite. Bituminous coal may be divided according to the amount of volatile matter it contains into low volatile, medium volatile, and high volatile coal. Or it may be divided on the basis of original differences into caking, non-caking, and cannel coals. Coal may also be divided according to use as: steam, coking, smithing, and so forth. The percentage of gas or "volatile matter" in the coals of Pennsylvania decreases from west to east. The coals around Pittsburgh are "high volatile" or gas coals. Those in Fayette, eastern Westmoreland and Indiana counties are "medium volatile" coals, suitable for making beehive coke. "Low volatile" or "smokeless" coal occurs in Somerset, Cambria, Clearfield and Centre counties, and to the north and east. Still farther northeast are the anthracite fields where in general the gas or volatile matter in coal is

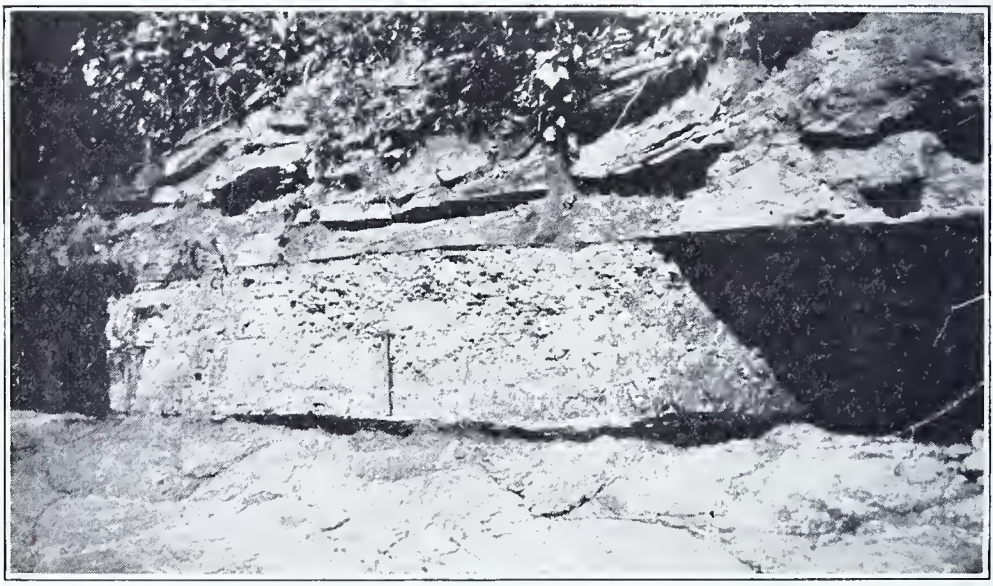


Fig. 74. Bed of coal overlain by a sandstone and lying on the underclay. Photo by H. H. Hughes.

less than 6 per cent. Semi-anthracite occurs in a small area in Sullivan County, between the anthracite and bituminous coal fields, and also at the western end of the Southern anthracite field.

Location. Anthracite occurs in four irregular basins (see map) in the northeast part of the State. These are called the Northern, Western Middle, Eastern Middle, and Southern basins or fields. The basins are the bottoms of folds into which the coal beds and adjoining rocks were thrown at the end of Carboniferous time. The upper parts of the folds were carried away during the long period of erosion that followed the folding.

Bituminous coal is found in the western part of the State and in hilltops in detached basins in the northern part of the State, as shown on the map.

Occurrence. Coal occurs in beds 1 inch to 100 feet thick, some of limited extent, some covering thousands of square miles. Most of the beds are from 1 to 4 feet thick. The total number of beds in Pennsylvania is about 60, of which only about 10 are widely mined.

Coal beds. The more important coal beds of the State are listed below by name. The Lykens bed (Nos. 2 to Lykens Valley) were laid down at the east while dry land prevailed in western Pennsylvania. The equivalence of beds between the anthracite and bituminous fields is tentative.

TABLE OF COAL BEDS IN PENNSYLVANIA

System	Series	Group		Bituminous Field	Southern Anthracite Field	Broad Top Field
PERMIAN	LOWER PERMIAN OR DUNKARD	Greene	e	Windy Gap		
			d	Gilmore		
			c	Nineveh		
			b	Hostetter		
		82	a	Dunkard		
		Washington	d	Jollytown		
			c	Washington A.		
			b	Washington		
8		81	a	Waynesburg A.		
PENNSYLVANIAN	UPPER PENNSYLVANIAN OR PITTSBURGH	Monongahela	e	Waynesburg	Lewis	
			d	Uniontown	Spohn	
			c	Sewickley	Clarkson	
			b	Redstone	Peach Mountain	
		79	a	Pittsburgh	Tracy	
		Conemaugh	j	Little Pittsburgh	Little Tracy	
			i	Franklin		
			h	Little Clarksburg		Rogers
			g	Wellersburg	Little Diamond	
			f	Barton	Diamond	
			e	Harlem	Little Orchard	McCue
			d	Bakerstown	Orchard	Mosquito Hollow
			c	Thomas		
			b	Brush Creek	Primrose	Phipps
		78	a	Mahoning		Speer
		Allegheny	c2	Upper Freeport	Holmes	Kelly
			c1	Lower Freeport		Dudley
			b3	Upper Kittanning		Barnettstown
			b2	Middle Kittanning	Mammoth	Twin Bed
			b1	Lower Kittanning		Barnett
			a3	Snodgrass	Skidmore	
			a2	Clarion	7 foot bed	Fulton
		77	a1	Brookville	Buck Mountain	Gordon

System	Series	Group	Bituminous Field	Southern Anthracite Field	Broad Top Field
PENNSYLVANIAN	MIDDLE PENNSYLVANIAN OR KANAWHA	Upper Kanawha 76	Tionesta Upper Mercer Lower Mercer		
		Middle Kanawha 75	Quakertown Sharon	Lykens No. 1	
		Lower Kanawha 74			
	LOWER PENNSYLVANIAN	Upper New River 73		Lykens No. 2 Lykens No. 3	
		Lower New River 72		Lykens No. 4 Lykens No. 5	
		Pocohontas 71		Lykens Valley	

Of the beds listed the Pittsburgh is commonly in two benches; the lower or main bench is 4½ to 9 feet thick. The Upper and Lower Freeports, and Lower Kittanning come next in importance with common thicknesses of 2½ to 8 feet, the latter only locally.

The Upper and Middle Kittanning are minable at many places, and in limited areas the Brookville, Clarion, Redstone, Sewickley, Uniontown, and Waynesburg, and beds below the Brookville are of commercial thickness, though generally thin. Most of the other beds named thicken up to 3 to 5 feet in spots.

The anthracite beds average much thicker than the beds of the bituminous field. In the Northern field most of the beds average better than 5 feet, the Dunmore 13 feet and the Baltimore 11 feet. In the Eastern Middle field the Mammoth is estimated to average 22 feet; most of the others range between 4 and 7 feet. In the Western

Middle field the Mammoth in four splits has an average aggregate thickness of about 38 feet; the Buck Mountain in three splits, about 23 feet; the Holmes 13 feet; the Primrose 12 feet; and the others less. In the Southern field the Mammoth averages 36 feet (114 feet in one place), and the others from 13 feet down.

Depths of beds and mining. Coal beds in the bituminous fields commonly lie within 500 feet of the surface, increasing in the southwest to possibly 2,500 feet for the lowest coals under some of the hills in southwest Greene County. Mining in the anthracite fields exceeds a depth of 1,850 feet and the coal beds go to undetermined depths below that.

Structure. The anthracite fields lie in the eastern part of the State where the rocks are highly folded. Correspondingly the anthracite beds and associated rocks are today found to be highly folded, faulted or broken and locally much crushed. Nearly everywhere the beds

Fig. 75. Modern colliery (Marvine colliery) near Scranton. Notice lack of dust or smoke. It was in full operation when photograph was taken.

pitch into the ground at high angles and locally in places stand vertically or are overturned. In some places the beds are squeezed thin and in nearby places a great thickness of crushed coal may be accumulated. In general the folding and crushing is more intense at the south and east, and less to the north and west. The beds in the Northern field are much less disturbed than those in the other fields and yield very much less small coal, a distinct economic advantage.

The beds in the bituminous fields are mildly folded, the rocks usually being inclined less than 5° from the horizontal. There are two pronounced folds in the southeast part of the field, the Laurel Hill and Chestnut Ridge anticlines or arches. The folding becomes less toward the west, and northwest of Pittsburgh the beds have only a slightly-undulating rise to the north.

The Broad Top field is the bottom of a broad fold preserved in that area by being folded down enough to bring some of the beds below the old plane of erosion.

Fig. 76. Mining coal by machine. Note toothed chain driven by motor around frame that moves forward under coal as teeth cut channel in bottom of bed. The view here is specially lighted for taking the photograph. Normally miners work in semi-darkness. Photo. by U. S. Bureau of Mines.

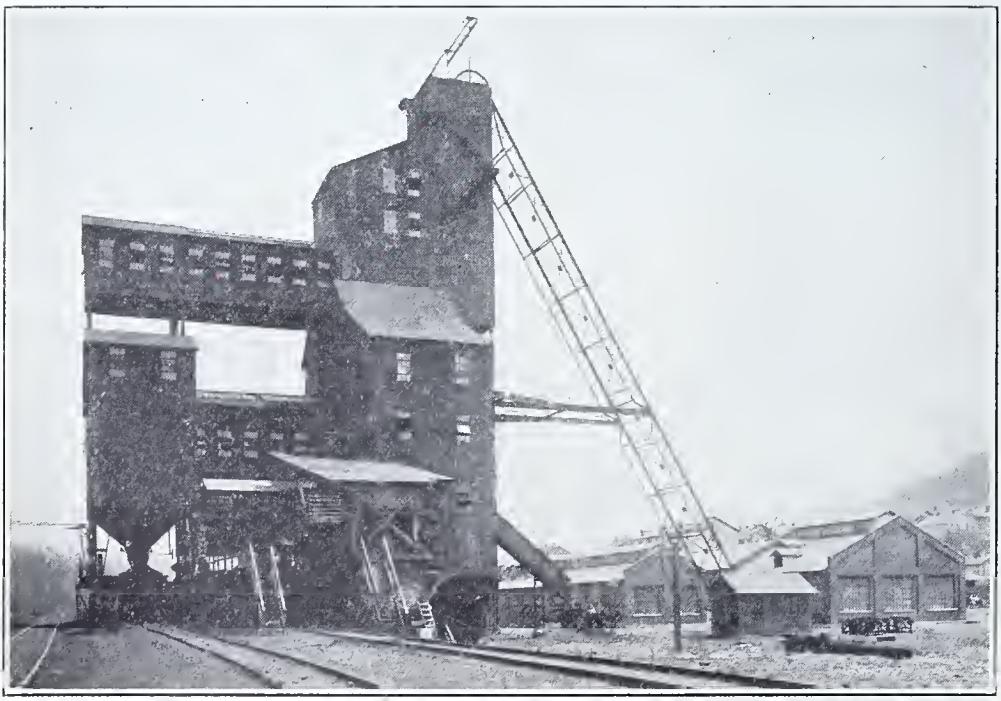


Fig. 77. A modern tipple, Allegheny County. The highest part of the tipple is over the mouth of the shaft. The hoisting cables descend from the large sheave wheels at the top to the hoisting house at the right. The tipple houses the screens and picking tables. Here the coal is weighed, as the miner is paid by weight. At the left is a storage bin. In the center is seen a chute for loading wagons for local consumption. In the central foreground are machine shops. The mining village is in the right background. Photo by U. S. Bureau of Mines.

Production and value. Anthracite mining began about 1810, rose to a maximum production of 99,611,811 short tons in 1917, from which production has declined irregularly to about 69,802,000 short tons in 1930. The high point in value was reached in 1923—$506,786,768, Taking 1923 as a typical year when the total production was 83,338,401 gross tons (93,339,009 short tons) valued as above, the decrease in production to 1929 is as follows:

Anthracite mined

	1923		1929	
District	*Long tons*	*Value*	*Long tons*	*Value*
Lehigh	11,745,042	$68,542,585	9,114,152	$52,052,035
Schuylkill	25,924,105	146,007,916	19,223,195	100,953,457
Wyoming	45,375,591	290,259,276	37,470,574	232,059,643
Sullivan Co.	293,663	1,976,901	110,110	577,616
Total	83,338,401	$506,786,768	65,918,031	$385.642,751

The bituminous mines produced in 1923

County	*Short tons*	*Value*
Allegheny	20,224,239	$54,521,000
Armstrong	5,061,732	13,710,000
Beaver	247,071	694,000
Bedford	597,496	1,849,000
Blair	169,276	516,000
Bradford	10,330	36,000
Butler	1,856,319	4,991,000
Cambria	19,751,465	59,213,000
Centre	1,356,503	3,897,000
Clarion	1,900,549	4,726,000
Clearfield	7,546,058	20,939,000
Clinton	260,551	642,000
Elk	1,147,125	3,385,000
Fayette	32,165,961	89,307,000
Greene	3,982,003	10,829,000
Huntingdon	757,678	2,798,000
Indiana	10,475,299	28,521,000
Jefferson	4,381,693	11,851,000
Lawrence	281,708	905,000
Mercer	465,349	1,409,000
Somerset	8,530.618	25,379,000
Tioga	480,335	1,813,000
Washington	24,499,103	61,406,000
Westmoreland	25,408,870	67,706,000
Other counties	83,625	326,000
Wagon mines on railways	283,957	848,000
Total	171,879,913	$472,217,000
Total for all fields	265,218,922	$979,003,768
Persons employed in bituminous coal mines,		194,981
Persons employed in anthracite coal mines		157,743
Total for State		352,724

Reserves:

Coal remaining in the anthracite fields (Ashmead)

Fields	*Total coal remaining, long tons*	*Est. per cent. recoverable*	*Est. recoverable coal remaining, long tons*
Northern	3,276,763,000	67	2,195,431,000
Eastern Middle	248,628,000	69.4	172,548,000
Western Middle	3,573,025,000	58.1	2,075,928,000
Southern	9,256,260,000	49	4,535,567,000
Total	16,354,676,000		8,979,474,000
Estimated recoverable within next 40 years			3,907,900,000
Estimated reserve beyond 40 years			5,071,600,000
Total			8,979,500,000

It is of interest to note that the anthracite mines produce annually a volume comparable with the French exeavation in the Panama Canal cut, and the bituminous mines about equal the rock taken out of that cut by the Amerieans.

Bituminous Coal Resources in Pennsylvania by Counties in short tons (Reese and Sisler)

County	Original deposit	Mined out and lost	Recoverable after dedueting estimated losses
Allegbeny	3,194,820,000	969,200,000	1,498,948,000
Armstrong	3,750,700,000	107,290,000	2,491,100,000
Beaver	1,261,797,000	7,650,000	651,517,000
Blair	78,516,000	23,900,000	36,508,000
Bradford	44,440,000	14,500,000	15,514,000
Broad Top Field	414,954,000	41,850,000	252,918,000
Butler	4,154,807,000	39,300,000	2,257,511,000
Cambria	5,383,000,000	466,900,000	3,638,080,000
Cameron	61,560,000	235,000	33,561,000
Centre	514,485,000	75,250,000	275,076,000
Clarion	2,042,800,000	60,000,000	1,262,300,000
Clearfield	3,992,000,000	308,210,000	2,165,400,000
Clinton	114,380,000	17,221,000	54,580,000
Elk	559,781,000	54,775,000	300,473,000
Fayette	5,229,734,000	899,544,000	2,604,400,000
Greene	9,464,215,000	42,390,000	6,276,251,000
Indiana	6,339,400,000	299,200,000	4,288,700,000
Jefferson	3,334,900,000	279,400,000	2,123,400,000
Lawrence	1,007,866,000	16,445,000	484,020,000
Lycoming	72,000,000	7,000,000	40,000,000
Mercer	499,680,000	80,000,000	224,540,000
McKean	422,865,000	1,615,000	226,303,000
Somerset	6,091,800,000	187,384,000	3,986,900,000
Tioga	155,432,000	48,000,000	55,660,000
Washington	10,526,023,000	557,763,000	5,481,680,000
Westmoreland	6,381,504,000	1,218,141,000	3,297,500,000
Total	75,093,459,000	5,823,163,000	44,022,840,000

Conservation. Large as this reserve appears on its faec it must be remembered that only about 10 billion tons (bituminous eoal) are in thick or moderately thick beds, such as are now being mined. If we continue to mine 150,000,000 tons a year, that 10 billion tons will be exhausted within 70 years and Pennsylvania will find herself with large reserves of thin eoal so expensive to mine she can no longer compete with adjoining States having much larger reserves of thiek, and therefore eheaply mined, coal. She is then likely to face a decline not only in eoal production, but in her vast metallurgical and manufaeturing industries now dependent on cheap eoal. When oil is exhausted we shall still make oil from oil shales and *coal.* When natural gas is exhausted we shall still make gas from *coal.* But when coal is exhausted our fuel resources are at an end, and we must turn to water, wind, wave, and sun, none of which will ever replace eoal in cheapness and ease of use.

By-products of Coal.

Coal is used today mainly in the raw state, but there is a steady drift towards some form of treatment of the coal before it is used. Among these may be mentioned briquetting, eoke making, low temperature distillation, and gas making.

Briquetting. Mining anthraeite results in the production of large amounts of small sizes, too small to be burned on an ordinary fire

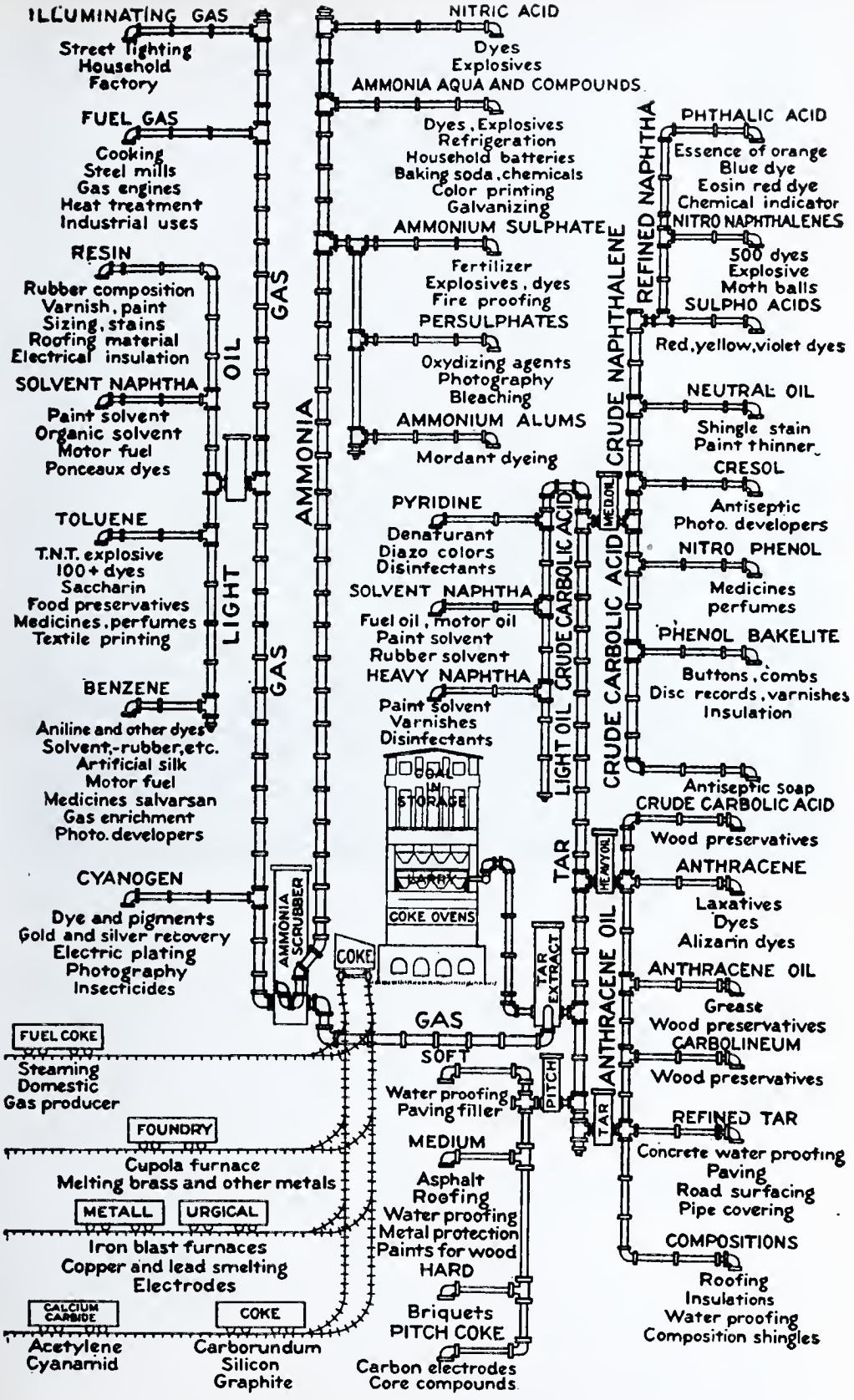


Fig. 78. Chart of uses of coal distillation products.

grate, in the ordinary way. Such coal may be rendered usable in an ordinary furnace by mixing with a small amount of binding material and compressing into briquettes. Several processes are in use, some involving a partial coking of the briquette after making. Pennsylvania in 1925 produced 115,138 tons of briquettes valued at $730,565.

Coke. Iron was first smelted with charcoal, then, in Pennsylvania, with anthracite or splint bituminous coal; about 1830 coke began to be made and used in Pennsylvania. Today with few exceptions, only coke is used in iron smelting.

Coke is made by heating coal in ovens or retorts out of contact with air. Under these conditions the coal does not burn, but the gas is driven out leaving the fixed carbon and ash of the coal, as a firm, porous fuel, suitable for blast furnace use. In the old days, rows of ovens shaped like beehives were used, and the gas and other materials

Fig. 79. A modern by-product coking plant, Rosedale, in Johnstown, Cambria County.

went off into the air. Then by-product ovens were introduced, in which the gas was drawn off and its various constituents separated and saved. By various processes of distillation, it is possible to separate out over a thousand useful materials, from paints to perfumes, from paving tar to gas for the household range. Coke from bituminous coal is increasingly replacing anthracite for household heating and other uses.

Production and value of coke in 1923 and 1928.

	1923		1928	
	Short tons	*Value*	*Short tons*	*Value*
Beehive coke	16,438,539	$94,923,942	3,442,006	$11,515,365
By-product coke	9,185,747	43,520,249	13,475,349	51,132,406
Total	25,624,286	$138,444,191	16,917,355	$62,647,772

In 1925 by-product coke in Pennsylvania exceeded beehive in quantity, and in 1926 surpassed beehive coke in Pennsylvania in both quantity and value.

Production and value of by-products in 1924.

	Produced	*Sold*	*Value*
Coke oven tar	.....	124,422,164 gals.	$4,728,802
Ammonia	294,325,226 lbs.	307,419,220 lbs.	6,945,306
Crude benzol	1,368,339 gals.	1,413,504 gals.	291,781
Refined benzol	3,228,653 gals.	3,226,541 gals.	690,474
Motor benzol	22,887,745 gals.	23,195,406 gals.	3,437,348
Toluol	1,008,160 gals.	1,046,248 gals.	239,803
Solvent naptha	1,462,569 gals.	1,506,411 gals.	253,584
Crude light oil	37,705,872 gals.	130,374 gals.	13,550
Coke-oven gas	138,625,989 M.	81,435,728 M.	8,793,586

Manufactured gas. In addition to natural gas and by-product coke gas used in Pennsylvania, 24,233,794 M. of gas were manufactured in Pennsylvania as a primary product. This had an average value of $1.16, per M. (1,000 cubic feet) or a total value of $28,011,200. Manufacturing gas yields tar, ammonia and other substances as by-products, as from by-product coke manufacture.

Low temperature distillation. Experiments in the low temperature distillation of coal are being made in many parts of the United States and elsewhere, though production is not as yet on a commercial basis. The result is a semi-coke or "char" which in some of the processes resembles anthracite chemically, if not physically, and as by-products a much larger proportion of high gravity oil or tar than in the ordinary process of making coke or coal gas. The primary purpose of low temperature distillation is the production of a smokeless fuel from bituminous coal. In Germany in particular, special attention has been given to processes by which a large part of the coal is converted into oil, which may take the place of petroleum in making gasoline and other petroleum products. It may be anticipated that in the years to come these processes will be perfected and that an ever increasing proportion of the coal mined in Pennsylvania will be converted into a smokeless fuel, or into oils for use in motor vehicles and for other purposes.

OIL AND GAS

General. Oil and gas are products of decomposition of vegetable and animal matter in the rocks. While coal is believed to be derived from the partial decay of woody and peat-forming plants, as a rule growing in place, oil and gas are thought to be derived mainly from sea weeds and other gelatinous plants with animal additions accumulated in water along with mud or other deposits. Such a deposit of mud and plant material when hardened into rock is called an oil shale, because if heated to the proper temperature in a retort, oil is driven off, possibly a barrel or more of oil to a ton of shale. If such a shale is subjected in nature to moderately high temperatures and pressures, oil may be distilled out of the plant material in the shale. Such oil tends to find its way to an open-grained sandstone, or other porous rock, and there accumulate, held in by a nonporous cover and waiting to be released by the drill. Generally both oil and gas are produced by distillation, the gas furnishing the pressure which drives the oil into and up a well when the "oil sand" is pierced. As the gas pressure declines with the withdrawal of the gas, the oil well ceases to flow.

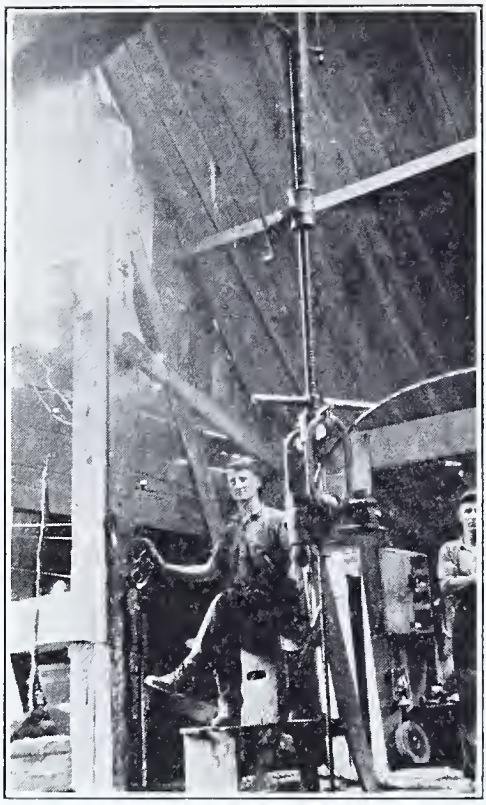


Fig. 80. Drilling what was at the time the world's deepest well. Notice the manner of holding drilling cable and screw used for lowering drill as hole deepens. Cable is lowered by turning screw. When screw is all payed out the cable is clamped and held at the floor the screw wound up and a new hold taken on the cable below the screw.

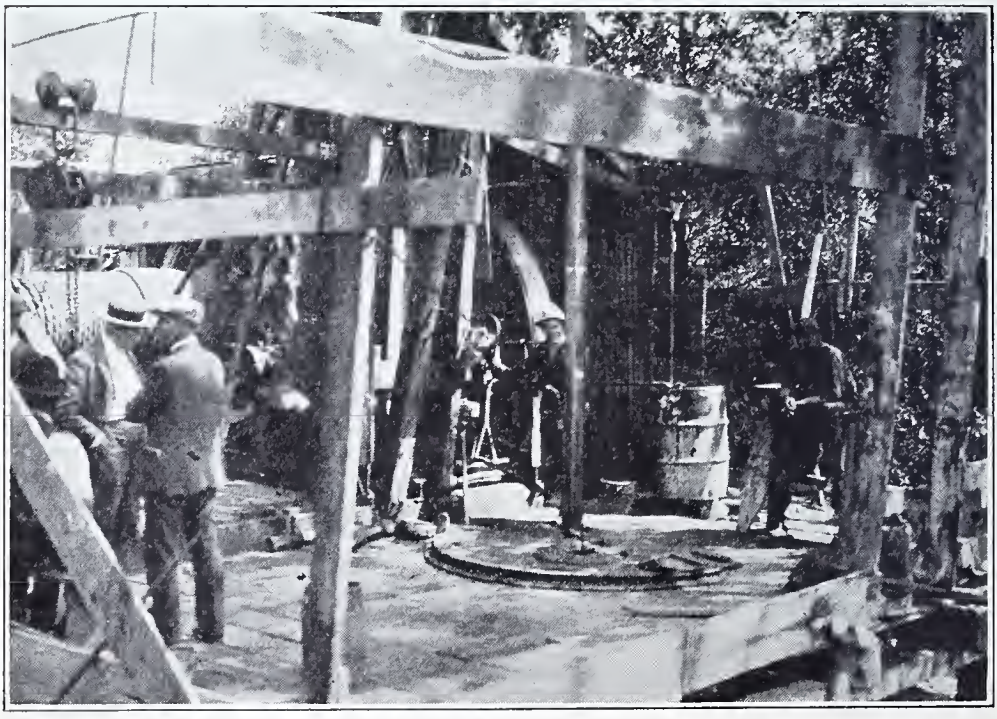


Fig. 81. Open drill house. Bradford field, showing drill raised above floor, cable at left.

If the pressure and temperature pass a certain point, the original vegetable material, called "kerogen," is converted not into oil and gas, but into gas only. This explains why in Pennsylvania the oil fields are in the west end of the State only, where the coals are "high volatile coals," and a broad gas field lies east of the oil. If the pressure due to the folding of the rock makes the temperature still higher, the gas is dissipated through the rocks into the air, and the rocks are found to contain neither oil or gas. This condition is true of all of the rocks east of Allegheny Mountain.

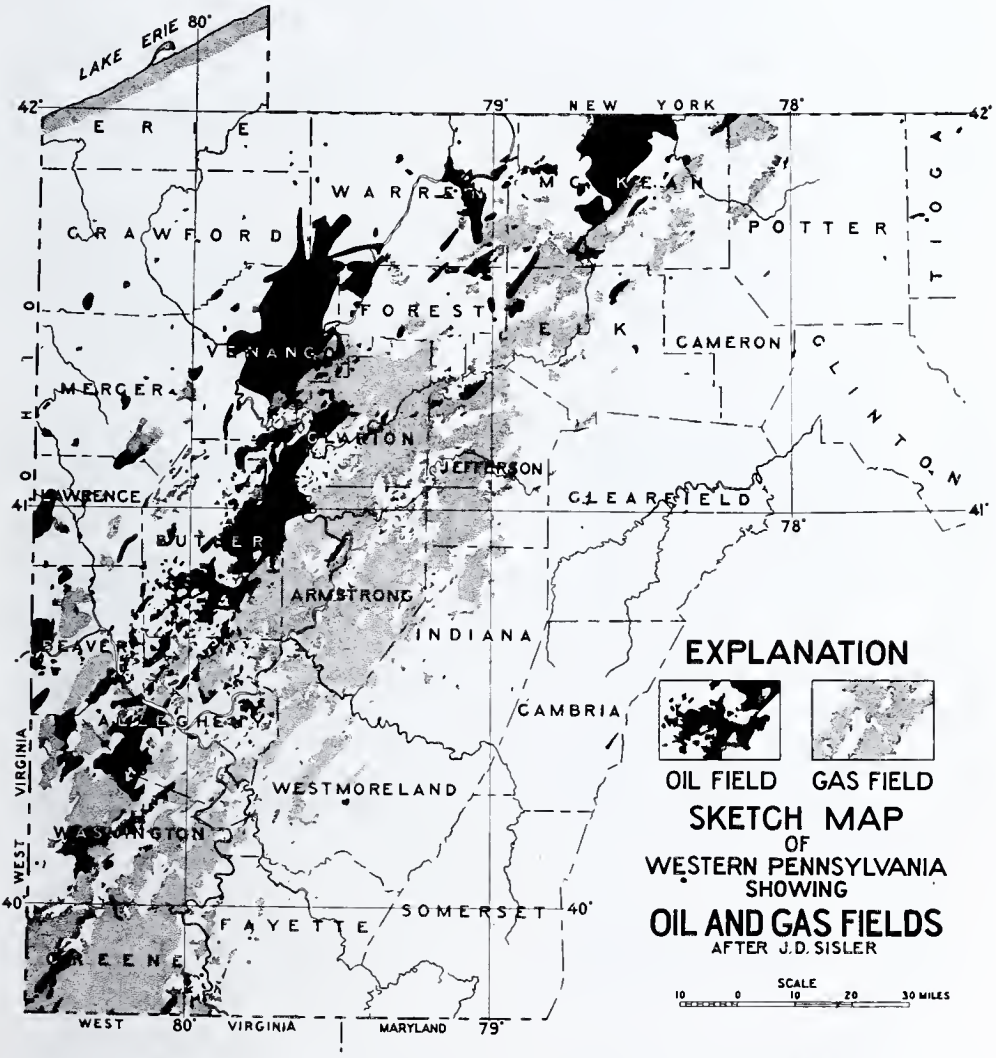


Fig. 82. Generalized oil and gas map of Pennsylvania.

Oil and gas sands. Oil and gas in Pennsylvania occur in porous sandstones of Pennsylvanian, Mississippian, Devonian, or Silurian age at depths from 50 to nearly 7,500 feet. A hole drilled in Pennsylvania to a maximum depth of 7,756 feet, struck gas at 7,430 feet. This well, at McCance, Westmoreland County, was when drilled the deepest well in the world. Now, a well at Kane is 8,100 feet and wells in Texas and California go to 9,500 feet. Most wells in Pennsylvania are from 500 to 3,000 feet deep. The following table shows the named oil and

Table of Principal Oil and Gas Sands of Pennsylvania.

Age	System	Series	Group	Name where outeropping	Drillers' names	Average distance below Pittsburgh coal
CARBONIFEROUS	PENNSYLVANIAN	PITTSBURGH	Monongahela	Pittsburgh coal	Pittsburgh coal	0
			Conemaugh	Morgantown sandstone Saltsburg sandstone Mahoning sandstone	Murphy sand Little Dunkard sand Big Dunkard, Hurry Up, Cow Run sand	150 360 550
			Allegheny	Upper Freeport coal Freeport sandstone Kanport limestone Clarion sandstone	Upper Freeport or Connellsville coal Second Cow Run sand Ferriferous limestone Gas sand	650 689 850 875
		POTTSVILLE	Beaver River	Homewood sandstone Conoquenessing sandstone Sharon (Olean) sandstone	First Salt sand Second Salt sand Lower salt, Maxton sand	930 1,000 1,100
	MISSISSIPPIAN	CHESTER	Mauch Chunk	Greenbriar limestone Red shale	Little lime, Mountain limestone Pencil cave	1,225
		MEREMEC	Ste. Genivieve	Loyalhanna limestone	Big Lime, Keener sand	1,250
		WAVERLY (POCONO)	Burgoon	Burgoon sandstone	Big Injun or Mountain sand	1,360
			Cuyahogo	Patton shale Sharpsville sandstone Sunbury shale	Red shale Squaw sand Papoose sand	1,600 1,630
			Berea	Berea (Corry) sandstone	Berea, First of Venango Co. Butler thirty foot, Murraysville, Gas, Salt sand	1,800 1,850

Table of Principal Oil and Gas Sands of Pennsylvania.

Age	System	Series	Group	Name where outeropping		Drillers' names	Average distance below Pittsburgh coal
DEVONO—SILURIAN	DEVONIAN	UPPER DEVONIAN	Venango	Venango (Salamanca) ss (?)	(Venango oil group and Berea)	Second of Venango group, Hundred foot, Gantz, and Fifty foot	2,000
						Red Valley (where split) sands Thirty foot, Nineveh thirty foot	2,150
						Snee, Blue Monday, Boulder Stray-stray, Hickory sand	2,180
						Gordon stray, Third stray, Campbell Run sand	2,200
						Gordon, Third of Venango group sand	2,250
						Fourth sand	2,325
						Fifth, McDonald sand	2,400
						Bayard, Sixth sand	2,475
						Elizabeth sand	2,550
			Chemung	Chemung (Cuba) ss (?)	(Warren oil group)	Warren First sand (local)	2,950
						Warren Second sand (local)	3,025
						Speechley stray	3,150
						Speechley, Glade	3,200
						Tiona, Clarendon	3,300
						Balltown, Gartland, Cherry Grove sandstone	3,400
				Chemung (Shumla) ss (?)	(Bradford oil group)	Sheffield, Cooper (?) sand	3,600
				Chemung (Leona) ss (?)		Bradford, Deer Lick sand	3,850
					(Elk oil group)	Smethport, Kane, Elk group etc., probably several horizons	4,200
		LOWER DEVONIAN	Oriskany	Oriskany sandstone		Oriskany, (At Ligonier 8,450)	6,500
	SILURIAN	MEDINA	Tuscarora	Tuscarora sandstone		Medina (At Ligonier 10,150)	8,300
						Clinton sand of Ohio.	

gas sands of Pennsylvania and their average depth below the Pittsburgh coal bed. The depth decreases toward the north and increases to the east. Thus, at Pittsburgh the interval from the Berea sand to the Bradford sand is 2,100 feet, but at Bradford, McKean County only 1,635 feet. At Pittsburgh the interval from the Pittsburgh coal to the Oriskany sandstone is 6,100 feet; at McCance near Ligonier, 8,450 feet, at Johnstown, 9,000 feet (estimated), at Altoona, 9,700 feet. The correlation of the Berea sandstone and the sandstone of Upper Devonian age with the oil sands is still the subject of study and may be changed in the future.

Occurrence. Oil and gas occur where the rock is fairly porous (more than 10 per cent pore space). The presence or absence of open pore space appears to be the principal controlling factor in Pennsylvania in determining just where within the oil and gas fields oil and gas may occur. Where rock is porous, which cannot be determined from the surface, oil and gas are most likely to be found on the anticlines or arch folds in the rocks. That is strikingly true where water occurs in the rock along with the oil and gas. The three arrange themselves in order, the water in the bottom or the troughs of the synclines, the oil above, and the gas at the top. Where this condition exists, and the sandstone is widely porous, it is possible by mapping the folds of the rocks to determine with much accuracy where oil and gas occur. In most of the oil and gas fields of Pennsylvania, however, there is no water in the sandstone, and the oil and gas are found in both the synclines and anticlines indifferently.

Oil.

Location. Found mostly in western part of the State (see map). Generally lacking in northwestern corner of State owing to lack of sandstones for reservoir rocks, and in central and eastern part of State because driven out by rock folding.

Production and value. Production began with the Drake well in 1859, reached a climax of 31,424,206 barrels in 1891, declined to 7,418,000 barrels in 1921, and rose to 11,804,800 barrels in 1929, owing to secondary recovery in the Bradford field.

Reserves. A recent estimate by the American Petroleum Institute, supplied the following figures:

Oil Reserves of Pennsylvania (American Petroleum Institute).

Area of Pennsylvania	28,880,640	acres
Producing area	380,000	acres
Proved but undeveloped	11,000	acres
Possible area	10,706,640	acres
Unfavorable	17,783,000	acres
Number of producing wells	76,664	
Production per day	20,628	bbls.
Total to date	708,318,000	bbls.
Estimated from present wells	80,000,000*	bbls.
From future wells	6,000,000*	bbls.
Total reserve from wells	86,000,000*	bbls.
Estimate left in ground	520,000,000*	bbls.

Much of this gas will doubtless be recovered sometime.

* See section on Mineral Reserves of Pennsylvania.

Natural Gas.

Location. In western and northern Pennsylvania in the same location as oil, but extending east to Allegheny Mountain. It occurs in rocks similar in occurrence to that of oil, but is found to greater depth and farther east.

Production and value. Natural gas statistics began in 1882. In 1906 production reached a high point of 138,161,385,000 cubic feet, valued at $18,558,245. Production dropped to 86,000,000,000 cubic feet in 1921. Under the spur of better prices, production has risen until in 1926 it was 107,809,000,000 cubic feet. The production in 1925 was 101,632,000,000 cubic feet, worth $47,098,000. Pennsylvania has 15,000 producing gas wells and 17,000 miles of pipes supplying 370 communities and villages. In 1929 the production was 101,951,000,000 cubic feet, valued at $28,189,000.

Natural Gas Gasoline.

Many gas wells in or near the oil fields are "wet," that is, the gas contains an appreciable amount of highly volatile oil. Gasoline is now being recovered from such wells by several processes. In 1920, 21,151,135 gallons of such natural gas gasoline, worth $4,382,380, was recovered. In 1928 the production was 16,571,000 gallons, worth $1,570,000.

Oil Shales.

Some bituminous shales occurring with the coal beds in the western part of the State will yield an appreciable quantity of oil upon distillation. Some of these shales that resemble cannel coal range in oil production per ton of shale from 1 or 2 gallons just west of Allegheny Mountain to about 40 gallons for certain shales in Beaver County close to the Ohio State line. Such oil shales as a rule are of limited extent in Pennsylvania. Cannel coal associated with these shales yields as high as 46.9 gallons of oil per ton of coal, and bituminous coal of the Pittsburgh region yields up to 34.3 gallons of oil per ton of coal. About the middle of the last century the production of oil from bituminous coal, cannel coal, and cannel shale was very active in the western part of Pennsylvania, centering a short way north of Pittsburgh. Oil is not distilled from shales in this State at present.

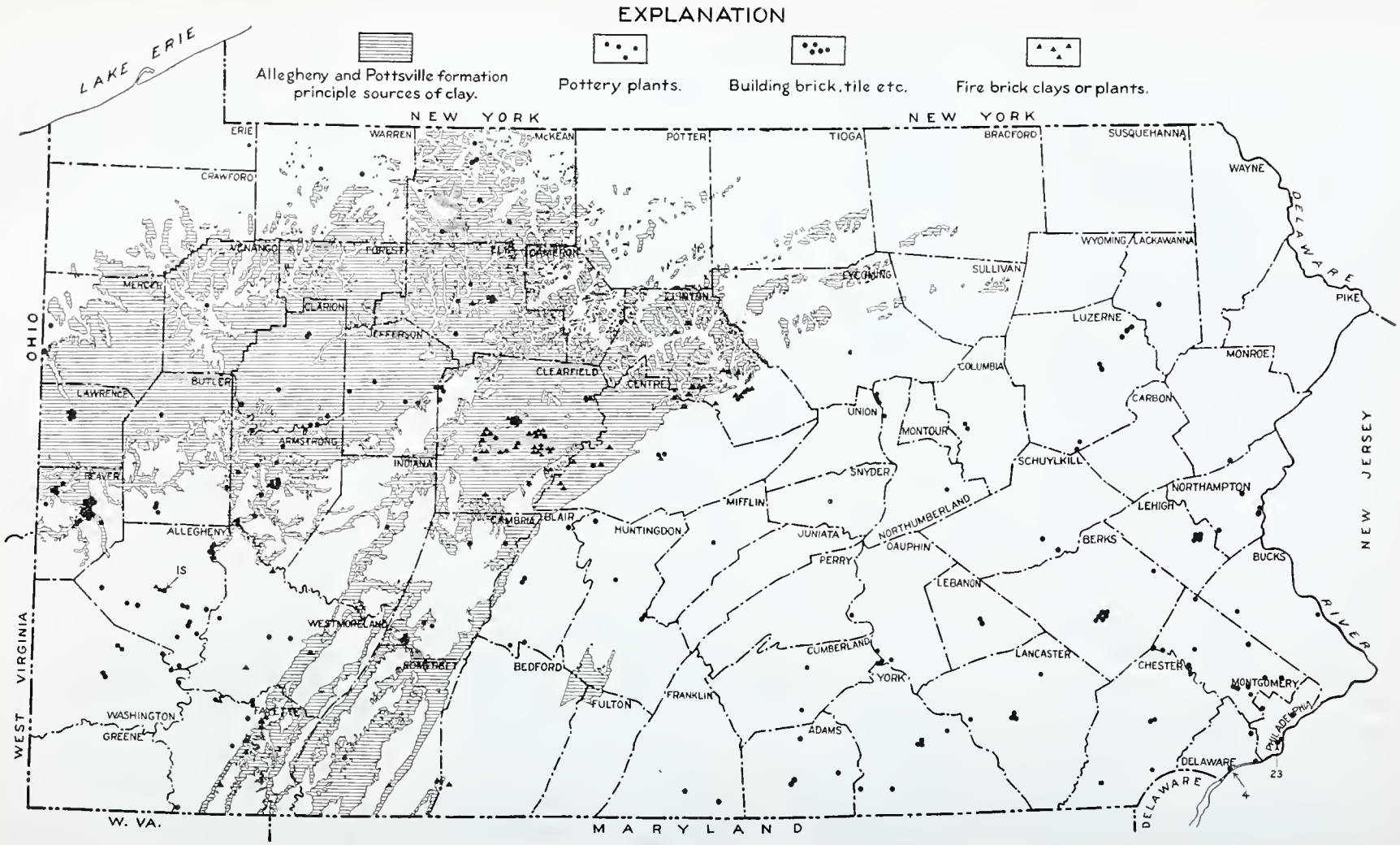
STRUCTURAL MATERIAL.

Clay and Clay Products.

Pennsylvania produces about one-eighth of all the clay products made in the United States. She stands second to Ohio among the States with pottery included.

Clays and clay rocks occur in every county in the State. The principal sources of clay in the State, however, are the clays underlying the coal beds, and shales associated with the coals, the red shales of Catskill, Salina and Clinton age in central Pennsylvania, the dark shales in central and eastern Pennsylvania of many ages, and the kaolins of southeastern Pennsylvania.

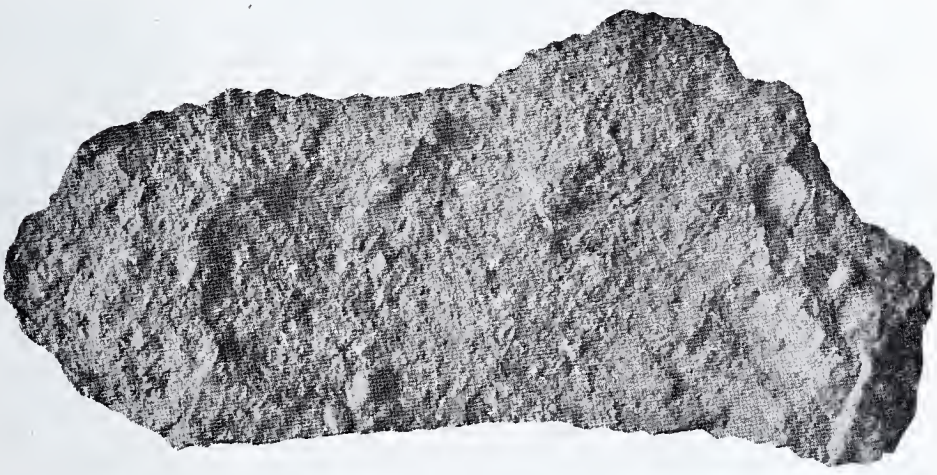
Fire clays and fire brick (exclusive of silica brick). Fire clays do not soften or fuse at temperatures less than 3,000° F. (1,650° C.), and are therefore suitable for use in lining furnaces, kilns and stoves,



CLAY RESOURCES OF PENNSYLVANIA.

Fig. 83. State map showing distribution of Allegheny and Pottsville formations, and location of clay.

A. High grade flint clay. From west of Blue Ball, Clearfield County.



B. Nodular flint clay. From west of Curwensville, Clearfield County.

Fig. 84. Flint fire clay, after U. S. Geological Survey.

either plastered on or in the form of brick. The fire clay commonly used in Pennsylvania is a clay rock—flint clay—not at all clay like, but approaching in appearance, hardness, and fracture some limestones and flints. Flint clay is not plastic, so must be mixed with plastic clay for moulding into brick. The under clays of the coal measures are commonly semi-refractory and are used for this purpose.

Flint clays are confined to a few horizons in the Allegheny group and Pottsville series. Mines on these clays are therefore confined to the eastern and northern edges of the bituminous coal field, and to the flanks of Chestnut Ridge and Laurel Ridge (see map). Soft clays from the coal measures are used to a limited extent for fire brick not required to meet very high temperatures. These are mined principally in Beaver and Washington counties. The principal mines on flint clay are in Clearfield, Centre, Clinton, Cameron, Elk, Cambria, Westmoreland, and Fayette counties.

The clays under the coal beds range from 2 to 20 feet thick, commonly 2 to 4 feet, are very persistent, and are coextensive with the coal fields. The flint clays commonly occur as layers, lenses or pockets in the beds of soft clay, and may be limited to lenses a few feet long and a few inches thick, but more often are from 1 to 20 feet thick and have an extent of several acres, and locally of several hundred acres.

Kaolin and white clays. Kaolin and white clays are confined to the southeast corner of the State, where they result from the decomposition of pegmatite veins or from the weathering of slate or schist in place or the separation and accumulation of the pure clay under water. Kaolins from pegmatites are found only in Chester and Delaware counties. White clays from the decay of shales, slates and schists of Canadian or Cambrian age are found or mined in Chester, Lancaster, Cumberland, Adams, Franklin and York counties, and in Nittany Valley of central Pennsylvania. White clay from the decomposition of Lower Devonian shale is mined in Monroe County.

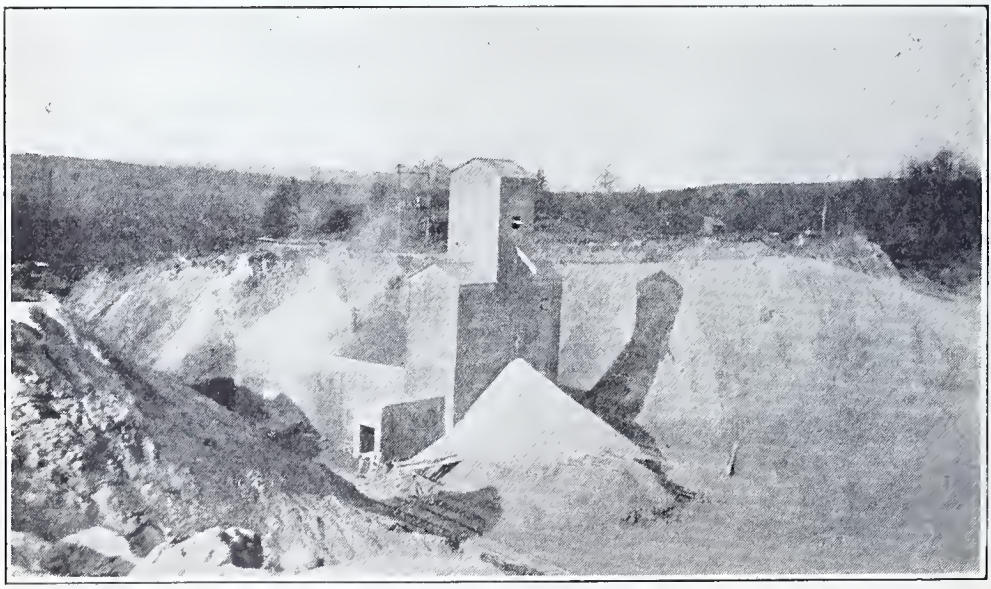


Fig. 85. White clay pit near Narvon, Lancaster County. Photo by R. W. Stone.

Clays and shales for brick, tile and terra cotta. These clays may be derived from the weathering of shales in place or from the separation and accumulation of pure muds along stream bottoms, or abandoned stream terraces; the clays and shales of the Coal Measures and other rock strata may also be used. Different uses demand clays of different character.

Clays and shales suitable for making brick and tile are widely distributed over the State. There are brick plants in all but 12 counties. They are most abundant in Beaver and Allegheny valleys, and in southeastern Pennsylvania.

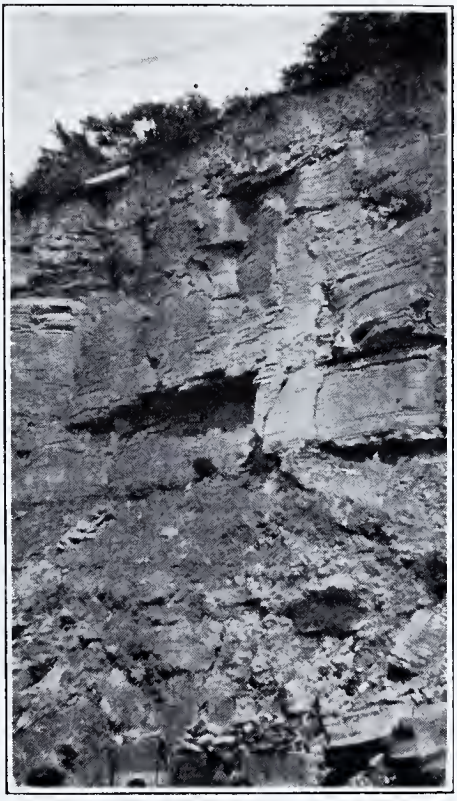


Fig. 86. Wall of quarry using shale and clay for brick and tile, at Homestead, Allegheny County. Photo by M. E. Johnson.

The following figures show the production in 1923 of raw clay (only that sold), of pottery and of clay products and non-clay refractories.

Production and value of all clay products.

	Value
Raw clay sold, 172,771 tons	$838,848
Pottery:	
Red earthware	411,449
Stoneware	356,175
Sanitary ware	2,069,243
Saggers	69,031
Chemical porcelain, white ware, hotel china, porcelain electrical supplies	4,821,194
Miscellaneous	125,000
Total	$7,852,092

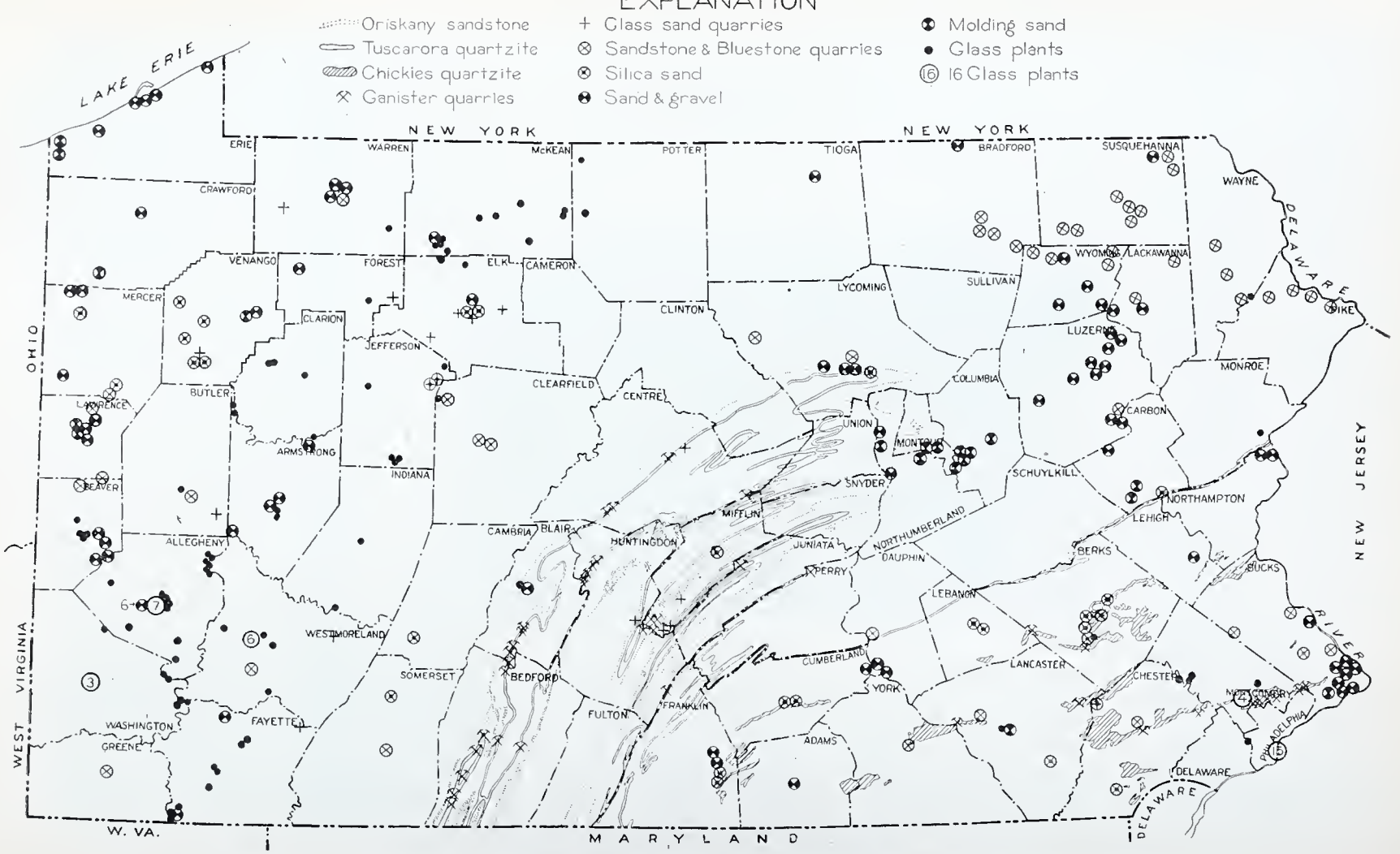


Fig. 87. State map, showing distribution of sand, gravel and sandstone quarries.

Clay products and non-clay refractories (other than pottery).

	Quantity	Value
Common brick	639,575 M.	$10,458,327
Paving brick	70,188 M.	1,766,402
Vitrified brick	10,074 M.	174,935
Face brick	468,910 M.	9,797,343
Hollow tile	211,929 tons	1,516,204
Floor tile	102,142 tons	621,249
Wall tile	5,604,747 sqs.	1,893,401
Sewer pipe	139,025 tons	2,269,523
Stove linings	11,705 tons	223,230
Fire brick	444,743 M.	19,208,240
Miscellaneous	.....	1,565,569
Silica brick	190,139 M.	9,139,863
Magnesia and magnesia brick	80,427 M.	2,741,101
Refractory cement	60,255 tons	934,292
Total (including raw clay)		$65,500,819
Total (with pottery)		73,352,911

Sand, Gravel and Sandstone.

Sand in its many forms finds many uses; for making glass, molding metals, for scouring and polishing, in soap, wood fillers, and

Fig. 88. Sand and gravel pit near Warren, typical of deposits found and quarried along most river valleys leading from the glaciated area.

paints, for lining acid steel furnaces, in mortar and concrete, for paving, and in pottery. Sandstone is used for building and paving, as grindstones and whetstones, and for crushing to sand.

Sand. Pennsylvania leads the world in glass making. Glass sand is obtained from the Oriskany sandstone in central Pennsylvania, and from the Pottsville sandstone, in a belt from Potter, McKean, and Warren counties southward to Westmoreland and Fayette. The best glass sand is over 99 per cent silica.

Molding sand is used in casting metals. It is commonly a mixture of sand and loam that will hold its shape when moist. Molding sand comes mostly from river and lake deposits. Silica sand made by crushing sandstone is used for casting steel.

Fig. 89. Glass sand quarry and plant near Mapleton, Mifflin County. Notice the nearly vertical position of the bed, the even bedding planes, and the whiteness of the sand.

Fig. 90. Digging disintegrated sandstone (Oriskany) for molding sand, near Montoursville. Photo by R. W. Stone.

Fig. 91. Mining sandstone underground for use as silica sand, West Winfield, Butler County. Photo by R. W. Stone.

Fig. 92. Quarrying Pottsville sandstone for building stone, Koppel, Beaver County. Photo by R. W. Stone.

Fig. 93. Flagstone quarry at Black Walnut, Wyoming County. Photo by R. W. Stone.

Fig. 94. Ganister rock covers the mountain side. Lewistown Narrows, near Lewistown, Mifflin County.

Gravels. Sand and gravel, for building, paving and engine use are usually obtained by dredging from river bottoms, banks, and terrace deposits. Most of the rivers supply some sand for these uses. Crushed sandstone and quartzite properly sized supply much of the sand used for grinding, polishing, furnace lining, and filter beds, as well as for building purposes.

Sandstone. Sandstone is used locally for building all over the State. The largest producers are near Curwensville, Clearfield County, and near Ellwood City on Beaver River. The stone in both places is the Homewood, or Upper Pottsville sandstone. A high grade sandstone is being quarried near Waynesburg, Greene County.

Northeastern Pennsylvania has a considerable industry in flagstone, which is a thin-bedded sandstone of Devonian age. Formerly this was much used for sidewalks, but today it is used mostly for interior floors, terraces, courts, garden walks, and stairs.

Ganister and silica brick. The quartzites at the base of the Silurian and at the base of the Cambrian have been found highly suited for making silica brick used for furnace lining. The former occurs in central Pennsylvania, where it makes most of the high mountain ridges. The latter is found only in southeastern Pennsylvania.

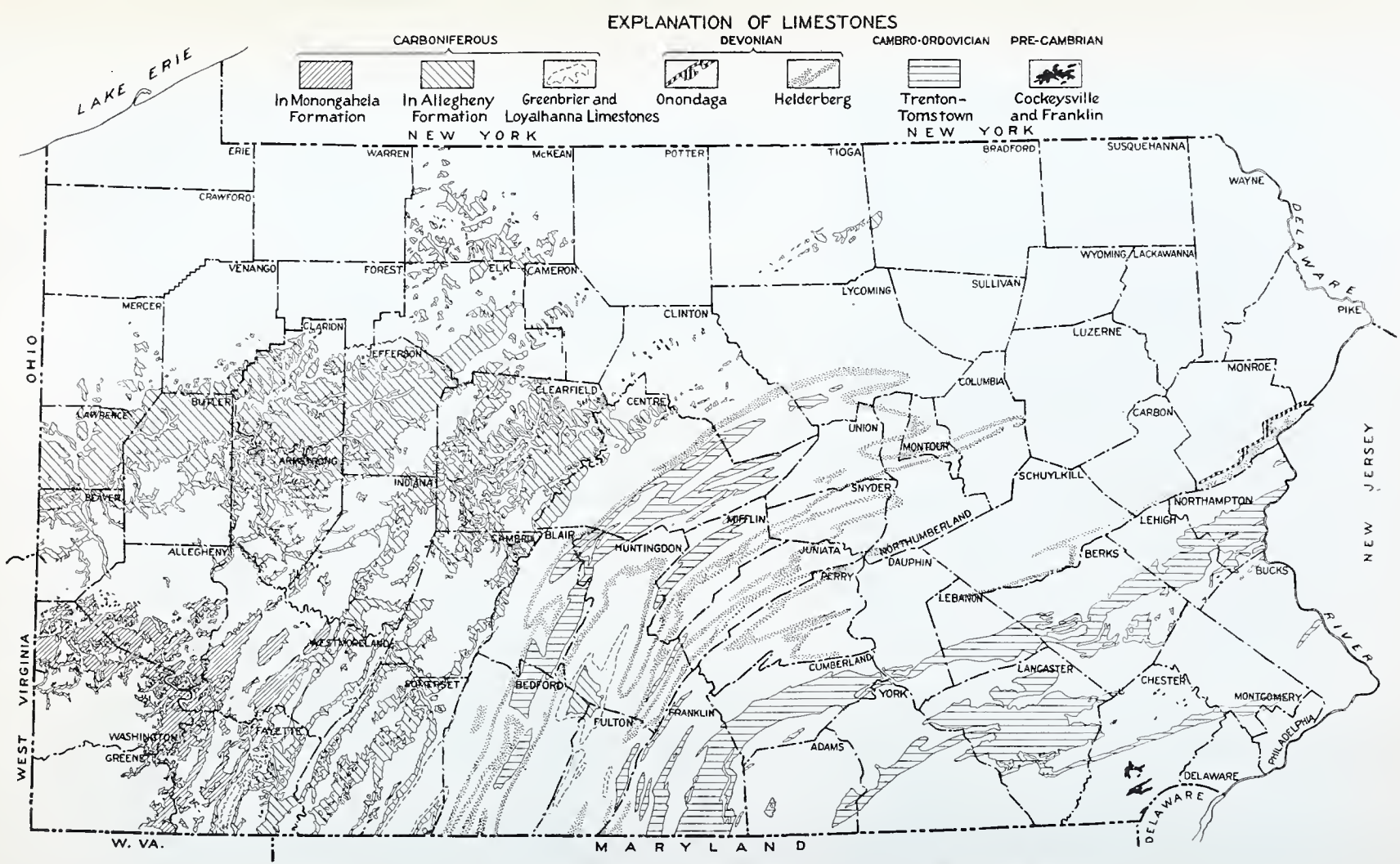
Sand and gravel produced in 1928

	Short tons	*Value*
Glass sand	451,014	$906,350
Molding sand	379,493	561,217
Building sand	3,900,967	3,106,845
Paving sand	2,610,945	1,913,302
Grinding and polishing sand	448,859	509,047
Fire or furnace sand	40,809	54,476
Engine sand	353,582	382,499
Building gravel	2,885,858	2,529,239
Paving gravel	1,792,826	1,290,846
Railroad gravel	62,273	13,887
Other sands	29,164	22,118
Total	12,955,790	$11,289,826

Sandstone produced in 1928

			Value
Rough construction	tons	28,090	$73,583
Rough architectural	cu. ft.	34,240	29,156
Dressed, sawed and cut	cu. ft.	21,120	88,386
Refractory stone, ganister	tons	558,340	721,555
Paving blocks	number	1,750,310	125,841
Curbing	cu. ft.	195,250	167,286
Flagging	cu. ft.	158,280	154,379
Rubble	tons	9,320	27,377
Riprap	tons	(1)	(1)
Crushed stone:			
Concrete and road metal	tons	528,890	703,786
Railroad ballast	tons	268,580	320,410
Other uses		(1)	(1)
Undistributed			25,681
Total (approximate tons)		1,462,570	$2,437,440
Silica brick from ganister (1923)			10,629,739
Glass made in Pennsylvania (1923)			99,197,880

[1] Included under "Undistributed."



MAP OF THE LIMESTONES OF PENNSYLVANIA. AFTER MILLER.

Fig. 95.

Pennsylvania leads the United States and the world in the production of cement, producing about one-fourth of all that produced in the United States, and about one-tenth of the world's production. It stands second to Ohio in lime production, and second to Indiana (where is found the famous Bedford stone) in quarrying or mining of limestone.

Limestone 2 to 20 feet thick occurs at many horizons in the Coal Measures. The most important bed is the Vanport limestone near the base of the Allegheny group. The Helderberg limestone at the base of the Devonian is several hundred feet thick and widespread in central Pennsylvania. Limestones and dolomite dominate in the section from the top of the Middle Ordovician to the upper part of the Lower Cambrian. These older limestones outcrop widely in the Nittany

Fig. 96. Quarrying limestone near Billmeyer, Lancaster County.

and other valleys of central Pennsylvania, form a long belt from Easton to Chambersburg and beyond and underlie the Chester and other valleys in southeastern Pennsylvania (see map).

The following table shows the uses to which Pennsylvania limestone is put and the amount and value (1928) for each use.

Limestone produced in Pennsylvania in 1928

Use	*Tons*	*Value*
Rough construction	80,700	$ 101,196
Rubble	2,700	2,700
Concrete and road metal	4,883,090	5,901,807
Railroad ballast	74,560	81,590
Fluxing stone	7,459,710	5,991,367
Glass making	105,230	179,914
Paper mills	30,560	35,400
Agriculture	55,470	182,624
Other uses	356,100	598,568
Total	13,048,120	$13,075,166

Fig. 97. Vanport limestone quarried for flux at Bessemer, Lawrence County. Note stripping at right above quarry rock. Photo by R. W. Stone.

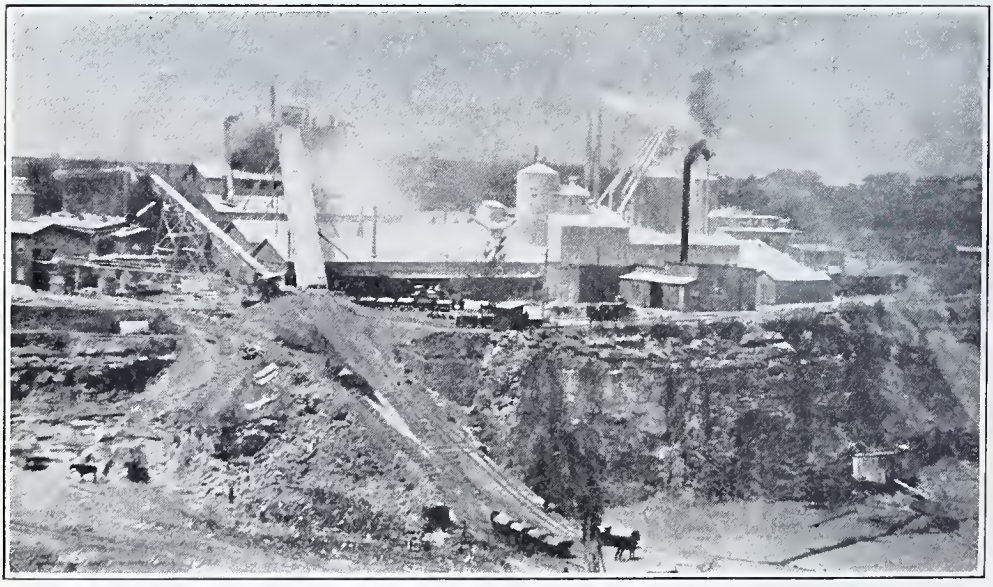


Fig. 98. Modern lime kiln near York, York County. Photo by R. W. Stone.

Pennsylvania has a small production of marble from the southeastern part of the State.

Lime. Pennsylvania alternates with Ohio in leading in the production of lime. In 1928 the State produced 834,050 tons of the total for the United States of 4,458,412 tons. The Pennsylvania product was valued at $6,119,036, out of the total value for the United States of $36,449,635. The following table shows the uses of lime and the production and value for 1928.

Lime produced in Pennsylvania in 1928

	Tons	*Value*
Building	251,056	$964,044
Agriculture	154,177	1,133,190
Glass making	(1)	(1)
Paper making	47,686	329,118
Sugar refining	(1)	(1)
Tanneries	20,912	157,330
Metallurgy	117,961	665,415
Other chemical uses	239,770	1,851,210
Undistributed	2,488	18,729
Total	834,050	6,119,036

In place of the old, small lime kiln found all over the State, lime-making is now confined mainly to relatively few large plants using continuous shaft and horizontal, rotary kilns, and using only pure limestone, such as the Stones River, Lowville and Vanport limestones. Many of these plants are today making hydrated lime.

Cement. Pennsylvania has long led in the production of Portland or hydraulic cement, a cement that will set under water. It consists of a mixture of lime, silica, iron oxide, and alumina ground fine and burned at about 3,000° F. to a clinker, then reground into

Fig. 99. Cement rock quarry. Face of quarry about 90 feet high. Quarrying is done by drilling line of 6-inch holes (note drill) a short distance back from face (note drill holes in face), after surface material has been stripped from top of rock. (Note steam shovel near drill). The drill holes are then charged and fired, throwing forward the whole face of the quarry along the line of the drill holes. Lehigh district, Pa. Photo by R. W. Stone.

the cement flour common in the market. In the Lehigh Valley a rock is used which is nearly the right mixture of clay and lime for making Portland cement, and needs only a slight addition of high grade limestone. In other places a mixture of about three parts limestone and one part clay or clay shale is used.

Portland cement plants are confined to the Lehigh Valley, Montgomery, York, Lawrence, Allegheny, and Butler counties. The Lehigh Valley plants use rock of Trenton age. Most of the rock used is too high in shaly material, and requires the addition of pure limestone. The other plants use high grade limestone and mix clay or shale with it. Those in the western part of the State use the Vanport limestone.

Natural hydraulic cement was first made in Pennsylvania, at Palmerton in 1826. In 1830 the plant was moved to Siegfried. In 1872 Portland cement was first made in the State at Coplay. From that, cement production in Pennsylvania has grown until in 1928, the production was 41,522,401 barrels, with shipments of 41,161,019 barrels valued at $62,572,588.

Marl is a calcareous deposit usually forming on the surface near limestone springs, and deposited in lakes or marshy areas. Where available, it is used for agriculture, in the same way as lime. So far only small deposits of marl have been found in Pennsylvania and these are confined to the limestone areas. The glacial marshes or lakes have not yet been studied. In other States these are found to contain considerable deposits of marl.

Granite and other Building Materials.

Granite, gneiss and schist occur in Pennsylvania only in the southeastern corner of the State. Gneiss and schist are widely abundant rocks underlying most of Philadelphia, Chester and Delaware counties,

Fig. 100. Granite in quarry at Seisholtzville, Berks County. True granite of Pennsylvania is intrusive through the other rocks. Photo by R. W. Stone.

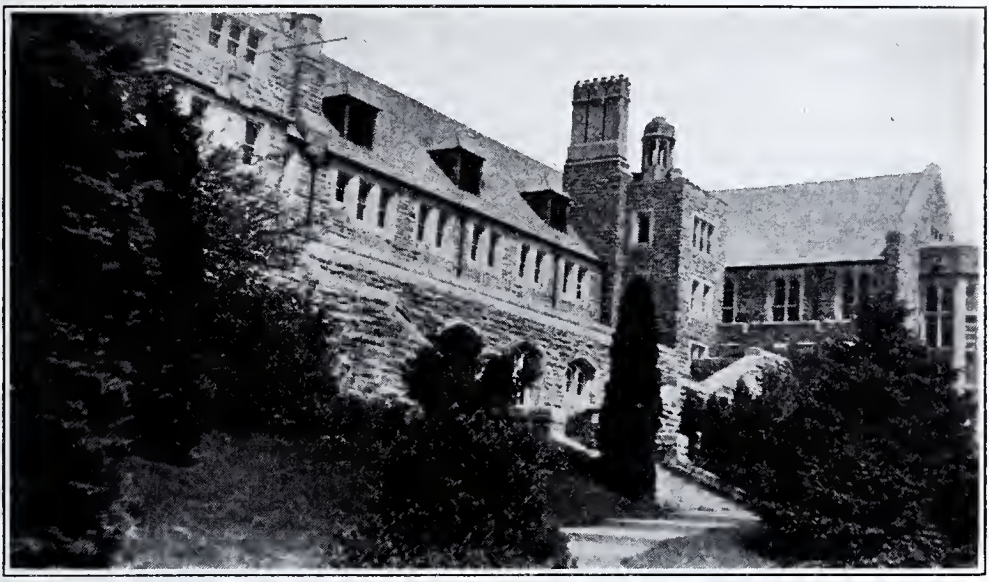


Fig. 101. An example of a building of Pennsylvania gneiss at Elizabethtown. Photo by R. W. Stone.

Fig. 102. Quarry in gneiss, at Cornog, Chester County. Photo by R. W. Stone.

and the southern parts of Bucks, Montgomery, Lancaster and York counties. Granite, gabbro, and diorite occur in the South Mountain of Berks and Lehigh counties. True granite is found at only a few localities where granite dikes have cut up through the older rocks. The gneisses of Pennsylvania were, as a rule, originally sedimentary rocks. The gneiss of some localities approaches granite in appearance and character, but most of it is definitely banded and streaked.

Gneiss and schist have an extensive local use as building stone in southeastern Pennsylvania and are shipped even outside of the State for this use. The term "black granite" is sometimes applied to diabase or trap.

The following figures include both granite and gneiss and an undetermined quantity of diabase and related rocks.

Production and value of granite in Pennsylvania in 1928

			Value
Rough construction	tons	117,970	$296,162
Architectural	cu. ft.	14,040	30,176
Monumental, rough		(1)	(1)
Monumental, dressed		(1)	(1)
Curbing		(1)	(1)
Rubble	tons	43,740	60,896
Paving blocks		(1)	(1)
Crushed stone:			
Concrete and road metal	tons	122,250	167,107
Railroad ballast	tons	40,000	75,031
Undistributed			75,031
Total (approximately)		328,330	$677,372

[1] Included under "Undistributed."

Trap, diabase, basalt, and rhyolite. These are all igneous rocks, some of pre-Cambrian age, a few of Paleozoic age, but mostly of Triassic age. Triassic diabase is confined mainly though not entirely to the Triassic belt in southeastern Pennsylvania. Trap, which is

Fig. 103. Quarrying diabase at St. Peters, Chester County. The finished product is usually marketed as "black granite." Photo by R. W. Stone.

the general name for rocks of this character, is a dark, heavy, fine-grained igneous rock much used for road metal and for monuments ("black granite"). Rhyolite and basalt, abundant in the South Mountain, have a permanent green and red color, and are extensively ground to granules for making roofing.

Production and value of trap and related rocks in Pennsylvania in 1928.

	Tons	*Value*
Rough building stone	8,460	$ 20,004
Rubble and riprap	1,250	1,986
Crushed stone:		
Concrete and road metal	937,290	1,213,312
Railroad ballast	421,610	510,299
Other uses	87,170	446,840
Total (approximately)	1,455,780	$2,192,441

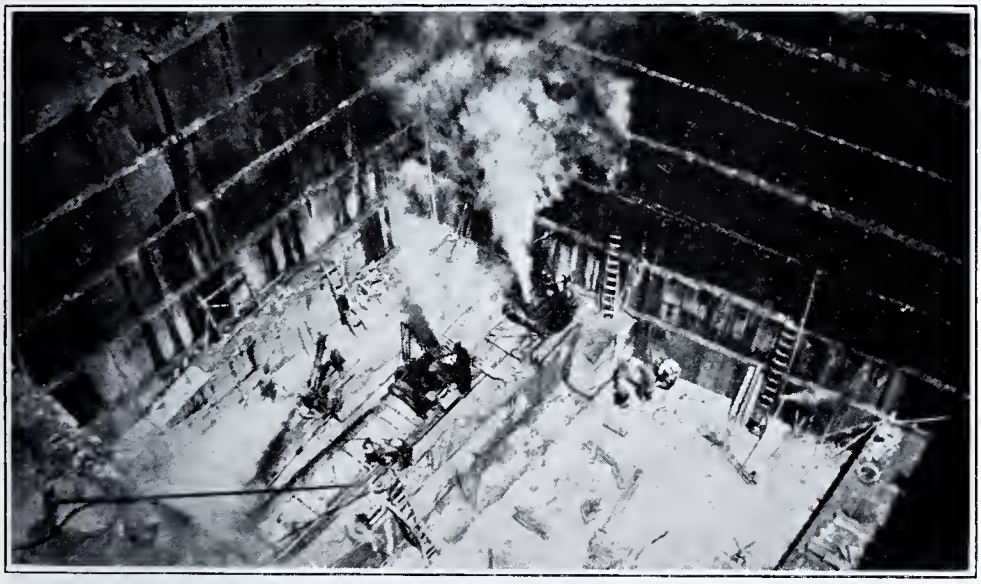


Fig. 104. Serpentine quarry near Delta, York County. Photo by R. W. Stone.

Serpentine occurs at a few places between Delta and Schuylkill River, and north of Easton. It has been quarried for building stone at Easton and in Chester and Delaware counties. It has an attractive green color, but it has not proved entirely durable in cities. The verde antique variety at Easton makes handsome stone for interior use. Figures of production in Pennsylvania are not available.

Talc occurs where serpentine is associated with the older crystalline rocks. It is quarried near Easton and ground to pulp for a variety of uses including the familiar toilet article.

Pennsylvania and New Jersey together produced 8,097 tons of talc in 1926 valued at $74,120.

Slate.[1] Slate is a metamorphosed shale. When shale is subjected to extreme pressure and folding its component particles are turned

[1] See Bulletin M9, List of Publications.

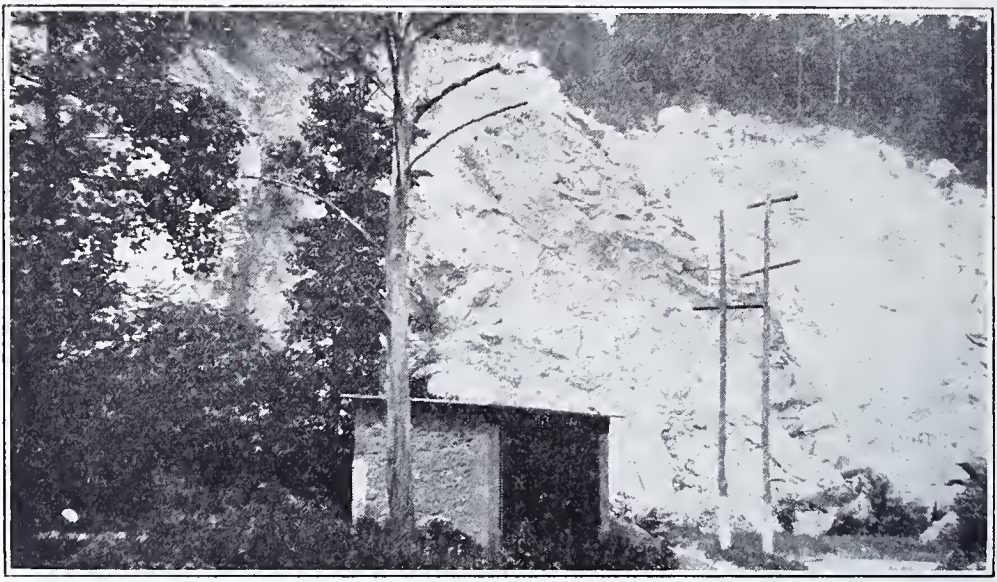


Fig. 105. Talc quarry north of Easton.

Fig. 106. Near view of blocks of talc, several feet in diameter.

at right angles to the direction of pressure so that the rock splits freely in planes following the new direction of the particles. Further, the shale is converted into a hard resistant rock that serves excellently for roofing, or, when cut and smoothed, for many other purposes. Recently slate colored and lacquered to resemble marble has come on the market.

Slate occurs in Pennsylvania mainly in Northampton and Lehigh counties (Martinsburg shale), and in the Peach Bottom district of Lancaster and York counties. The quarries, which follow the bands of good slate, may be several hundred feet deep. The slate belt of Northampton and Lehigh counties, from 7 to 13 miles wide, lies just south of Kittatinny Mountain. The rocks in this belt are several thousand feet thick and lie in three zones, including "hard slate" at the bottom, a zone of sandstone and slate in the middle,

Fig. 107. General view of Albion slate quarry, Pen Argyl. Note horizontal banding made by successive cuts of channeling machine, each cut about 12 feet high. Quarrying in progress on narrow shelf on farther side.

and a zone of "soft slate" at the top on the north side of the belt. A small amount of slate has been found in the Devonian rocks north of Kittatinny Mountain, and in Adams County, and other places. The "slate" of the coal fields is not true slate.

Production and value of slate in Pennsylvania

		1926		1929	
Roofing slate ----------squares	(100 sq. ft.)	263,668	$2,127,782	251,880	$1,967,428
Structural and sanitary --------	square feet	2,848,000	997,108	3,012,500	1,135,695
Electrical ----------	" "	488,125	327,447	340,530	219,761
Blackboards, etc. ----------	" "	3,908,653	1,356,300	3,562,360	1,042,771
School slates ----------	" "	972,767	32,886	949,540	20,371
Other* ----------			571,654		412,174
Total ----------			$5,413,177		$4,798,200

* Includes 337,430 square feet of billiard table material, valued at $128,441, and 64,770 short tons of granules and "flour" valued at $441,647.

Fig. 108. View at bottom of slate quarry, Bangor. Photo by R. W. Stone.

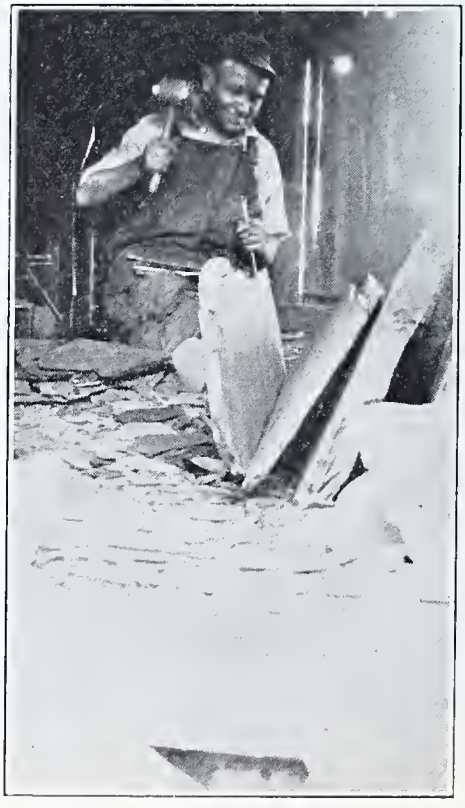


Fig. 109. Splitting slate for roofing, Belfast.

Iron.

Historical. Iron was mined and smelted in early Colonial days in Pennsylvania. At first charcoal was used as fuel, then anthracite, then coke. The industry grew rapidly, Pennsylvania taking and maintaining the lead in iron ore mining and in the production of pig iron until 1880. Before 1880 Pennsylvania was importing iron ore from other regions. The development of the great deposits in Michigan and Minnesota led to the abandoning of much of the iron ore mining in Pennsylvania excepting the magnetite ores of Cornwall, French Creek, and a few other localities. Pennsylvania,

Fig. 110. Old charcoal iron furnace on Allegheny River, Armstrong County. Photo courtesy U. S. Bureau of Mines.

however, continues to lead the United States in the production of pig iron and today is the greatest producer of pig iron in the world, the United States as a whole excepted. Iron ore is today imported from the four corners of the earth for the manufacture of pig iron in Pennsylvania.

Iron ores. There are four common ores of iron, magnetite or black iron ore (Fe_3O_4) theoretically 72.4 per cent iron; hematite or red iron ore (Fe_2O_3) 70 per cent iron; limonite or brown iron ore ($2Fe_2O_3,3H_2O$), 59.80 per cent iron; siderite ($FeCO_3$) 48.27 per cent iron.

Fig. 111. Cornwall iron mine looking east, toward incline hoists, wall of ore left to support railroad and Big Hill in distance, now worked out.

Fig. 112. Cornwall iron mine looking west, shows several terraces of mining. This pit is about a half mile long and 250 feet deep.

Magnetite is associated with the Triassic rocks and is found principally where igneous intrusions of that age have encountered limestones, hot waters carrying iron having dissolved the limestone and deposited iron in its place. Hematite occurs sparingly with the magnetite ores and as widespread beds of "red fossil ore" in rocks of Clinton age. It is therefore most abundant in the area of folded rocks in central Pennsylvania. Brown iron ore is widely scattered over the State in rocks of all ages. It is commonly a sedimentary accumulation or concentration by circulating waters which pick up iron from highly iron-bearing shales, sandstones, or other rocks and redeposit it at the surface or in other rocks, especially limestone which is dissolved as the iron is deposited. These ores were a large source of iron in the early days of Pennsylvania but have been little mined in recent years. Siderite is mined for paint ore in eastern Pennsylvania and was formerly mined in the form of nodules occurring in the Coal Measure shales of western Pennsylvania.

Present mining. During recent years iron mining in Pennsylvania has been confined to magnetite at Cornwall, Lebanon County, at Boyertown in Berks County, and at French Creek in Chester County. At Cornwall mining is by the open cut method using steam shovels, supplemented recently by underground mining. The Cornwall ore carries some other metals, notably copper, which is extracted as a by-product. The ores of French Creek were exhausted in 1928 and the mine abandoned.

It is supposed that considerable ore is still available in small bodies over the State, partly in deposits previously worked but not exhausted, partly in deposits not yet discovered, and partly in low grade deposits known but never worked. A little bog ore, a form of brown ore found in swamps, is dug and sold for gas purification.

In 1926 the production of iron ore passed the one million ton mark, with a production of 1,088,634 long tons valued at $2,483,056. In 1923 production was 993,441 long tons, divided as follows: brown ore 1,284 tons, magnetite 988,641 tons, and carbonate (siderite) 3,516 tons. In 1924 the Cornwall mine stood 13th in size of the iron mines of the United States and the French Creek mine 110th. The above figures of production are to be compared with 2,185,675 tons of iron ore produced in Pennsylvania in 1880 of which only 557,924 tons or 22 per cent was magnetite. In 1889 iron ore production had fallen to 1,560,234 tons of which 860,916 tons or 55 per cent was magnetite.

Copper.

The following are the principal ores of copper with their formulas and the percentage of copper contained:

Chalcopyrite ($CuFeS_2$) 34.5 per cent; chalcocite (Cu_2S) 79.8 per cent; bornite (Cu_5FeS_4) 55.5 per cent; cuprite (Cu_2O) 88.8 per cent; malachite and azurite, carbonates, 61 to 62 per cent.

All of these copper minerals have been found in southeastern Pennsylvania. Many attempts to mine copper ore have been made but have met with little success, though mines have been run for a time at several places. The principal localities are in the South Mountains of Adams and Franklin counties, in Chester, Lancaster, Berks, and other southeastern counties.

The present production of about 1¾ million pounds of copper is obtained by secondary recovery from iron ore. In 1927 the production was 1,735,800 pounds valued at $227,390.

Pyrite, Molybdenum, and Tungsten.

Pyrite and marcasite. Pyrite in small yellow crystals is often mistaken for gold. It is abundant in many of the rocks of Pennsylvania, and deposits of possible commercial value occur in the coal beds, where it is known to the miners as "sulpher," "sulphur balls," or "coal brasses." In some of the mines in western Pennsylvania there is enough pyrite to yield a ton of pyrite for each 100 tons of coal mined. Ordinarily this is wasted but at times, as during the war, it has been separated and sold for use in making sulphuric acid. It is not recovered at present.

Marcasite, or white iron pyrite, is common in limestones and shales. A common form in this state is round nodules with radiating internal structure. These round, heavy balls ranging in size up to 2 inches, are sometimes mistaken for meteorites.

Molybdenum and tungsten. No commercial ores of these metals, much used in steel alloys, have been found in this State. Specimens of several of the minerals containing them have been found, as molybdenite, molybdite, wolfenite, and scheelite. All of these have been noted in southeastern Pennsylvania.

Lead and Zinc.

Lead and zinc are not being mined in Pennsylvania today. Lead has been mined in Sinking Valley, Blair County, and near Phoenixville,

Fig. 113. View of zinc mine at Friedensville showing how the ore—in the worked out space—is interleaved with the limestone. This mine was about 300 feet deep when abandoned.

Chester County. Zinc was once extensively mined at Friedensville, Lehigh County. Ores are known or have been mined in Bucks, Lancaster, Montgomery, and Schuylkill counties. It is probable that some ores still exist at some of these localities.

Aluminum Minerals.

Several aluminum minerals occur in Pennsylvania aside from kaolin and other clay minerals. High alumina clay is associated with the flint clays of western Pennsylvania though not yet studied. Corundum, the oxide, occurs in the serpentine belt and was once mined at Unionville, Chester County. Cyanite, the silicate, is found as mineral specimens in Delaware, Chester, and Bucks counties. Epidote, a green mineral, usually an alteration product from other minerals, occurs in the greenstone of South Mountain, Adams County, in the Triassic belt, where shales have been altered by heat from trap, and elsewhere in southeastern counties.

Manganese.

Manganese is widely scattered through the rocks as a black stain. Its minable ores are principally pyrolusite and psilomelane. It has been mined at a few places, in connection with iron ore. No large deposits are known in this State. Imported manganese to the extent of 99,436 tons was refined in Pennsylvania in 1921. The value of all ferroalloys made in Pennsylvania in 1928 was $35,129,555.

Chromium.

Chromium, used in making chrome steel, occurs as chromite, a shiny black, hard and heavy mineral, in connection with serpentine. It has been mined near the Maryland line on Octoraro Creek in Lancaster County, and occurs also in Chester and Delaware counties. For several decades in the last century two mines in southern Lancaster County furnished almost the total world's supply. Together they yielded 220,000 tons. It is possible that these or other deposits will yield additional chromite. The ores are not being mined at present.

Nickel and Cobalt.

For many years Pennsylvania supplied all of the nickel mined in North America (1863-1888). This came from the mine near Gap, Lancaster County. It was first opened in 1732 and worked for copper. The ore showed from 1.10 to 2.26 per cent of copper, 1.53 to 4.23 per cent of nickel and cobalt. Nickel-bearing minerals have been found in a few other localities. Cobalt is reported from Phoenixville, Chester County, and Cornwall, Lebanon County. It has not been found in mineable quantity.

Gold and Silver.

Gold is obtained as a by-product in mining iron ore in Pennsylvania. It occurs sparingly with copper ores at Gap and Phoenixville, and in South Mountain. It is found in gravels along rivers flowing from glaciated regions. These deposits are of little or no value. The production of gold in 1928 as a by-product from iron ore mining was 992 troy ounces valued at $20,506.

Silver, like gold, occurs as a secondary product in lead and copper deposits. The present production is entirely as a by-product in the reduction of copper ores occurring in magnetite. Production in 1928 was 7,905 troy ounces valued at $4,624.

Radium Ores.

No commercial ores of radium are known in Pennsylvania. Carnotite occurs on Mount Pisgah near Mauch Chunk, Carbon County. Allanite, a "rare earth" radioactive mineral, occurs in granite at Allentown, near Reading, and in Chester and Philadelphia counties.

Mineral Paints.

Pennsylvania has long led in the production of mineral paints, using the oxides and carbonates of iron—ochers, umbers, siennas, and colored shales. Ocher—red, yellow or brown—comes from the brown

Fig. 114. View in paint mill where crude ochers are roasted preparatory to making into paint.

iron ores of the limestone valleys. Umber contains in addition to the iron a little manganese. Umber has been mined near Bethlehem, Doylestown, and west of Bethel, Berks County. A pulverulent, high-iron ore yielding sienna has been mined near Reading.

A bed of iron carbonate 2 to 4 feet thick, occurs at the base of the Marcellus black shale and has been mined since 1856 in southern Carbon County.

Black, yellow, and red shales from many horizons and many places have been worked in Pennsylvania for paint. Red iron ores have been mined in Union, Perry, Tioga, and Berks counties, and brown iron ore in Carbon County. Among minor substances entering into paint-making in Pennsylvania are graphite, soapstone and talc, pyrite and chromite, clay and kaolin.

Production figures are not available for recent years. In 1914 production was 9,862 tons valued at $121,888. Of this 3,799 tons valued at $34,223 was ocher.

Mortar Colors.

Mortar colors, used for tinting mortar, cement and concrete, are obtained from the same materials as those from which paint is made. They are usually mixed with other materials and may even contain coal from the anthracite culm heaps. In 1912 the production was 2,550 tons valued at $24,857. Figures for later years are not available.

NONMETALLIC MINERALS

Salts.

Salts of chlorine, bromine, and iodine occur in certain well waters of western Pennsylvania. Brines from wells along the lower Allegheny River were long worked for common salt and bromine. Bromine was first recovered in America at Freeport in 1846. Brine from near Saltsburg gave in parts per thousand: sodium chloride (common salt) 71.320; magnesium chloride 3.986; calcium chloride 15.726; bicarbonate of lime .005; bicarbonate of iron .078. Bittern (mother liquor) from Freeport gave in parts per hundred: potassium chloride 0.128; sodium chloride 0.887; calcium chloride 24.640; magnesium 2.575; bromine 0.701; iodine 0.0035. The last three are united with 6.886 parts of chlorine.

Bedded rock salt of Upper Silurian age is reported in several of the wells piercing rocks of that age.

Salt is not listed in the mineral production of Pennsylvania at present.

Graphite.

Graphite was mined in Pennsylvania as early as 1758. It has been mined at a dozen places in Chester County, and at places in Bucks, Lehigh, Montgomery, and Berks counties. It occurs mainly in gneiss of the same age as the pre-Cambrian Franklin limestone. This is highly metamorphosed mud which contained many impurities. Graphite occurs as minute flakes, often associated with flakes of mica, from which it is separated with difficulty. This difficulty may have led to the present suspension of mining. In 1910 production reached 1,861,000 pounds valued at $87,840.

Potash.

Potassium is an abundant element in the rocks of Pennsylvania, notably in certain feldspars and micas, and rocks containing these. Its extraction from such rocks costs too much to permit commercial development. Present sources are brines, natural flue dust from blast furnaces, and waste from molasses distillation. Potassium occurs in certain "greensands" containing the mineral glauconite. Such sands are abundant in New Jersey and may occur in southeastern Pennsylvania, though not now known. No commercial deposits of potash are known in Pennsylvania, but potassium salts are produced from flue dust at the Lucy and Isabella blast furnaces at Pittsburgh, and have been from the Lavino blast furnace at Sheridan, Lebanon County.

Phosphate Minerals.

Of many minerals containing phosphate only a few are sources of commercial phosphate. These minerals include apatite, pyromorphite, vivianite, and wavellite, which are found as mineral specimens, but not in commercial quantity, in many of the southeastern counties of the State. Deposits containing wavellite were once mined four miles west of Mt. Holly Springs in Cumberland County, but recent prospecting there failed to find any commercial deposits. In Juniata County near Reeds Gap nodular and white cellular or dense blue rock containing wavellite is said to carry as much as 12.54 per cent phosphoric acid. Wavellite was mined at one time at Whitehorse Station in East Whiteland Township, Chester County.

Asbestos.

Though not mined now asbestos was formerly mined near Rockdale, Delaware County, where it occurs in quartz veins. It is found in various places in the serpentine belt in Chester, Delaware, Lehigh, Lancaster, Montgomery, and other southeastern counties. Asbestos is a fibrous variety of amphibole and chrysotile, the latter, a variety of serpentine, being the common source.

Magnesia.

Magnesite, a source of magnesium, is found in Lancaster, Chester, Lehigh, Berks, and Delaware counties, but not in commercial quantities. Magnesia products, much used for fire proofing, refractory brick, furnace linings, etc. are made in Pennsylvania entirely from calcined dolomite. Dolomite is an abundant rock in the Canadian and Cambrian systems. Magnesia products to the value of $2,294,700 were made in Pennsylvania in 1921.

Barite.

Barite, barium sulphate, or "heavy spar" has been mined on a small scale near Chambersburg and Waynesboro, Franklin County, Fort Littleton, Fulton County, and in Berks and Montgomery counties. It occurs in the Helderberg limestone, and in other limestones, and is often plowed up in fields as noticeably heavy white lumps. It is not mined in Pennsylvania at present.

Feldspar.

Feldspar is a group name for a number of minerals used in making china and porcelain to control the fusion point of the mix, in scouring soap, in making emery wheels, and in certain kinds of glass and enamel. It is one of the three constituents of granite and occurs abundantly in gneiss and schist in southeastern Pennsylvania. Commercial deposits are in the form of dikes or veins of pegmatite. The veins are from 6 to 25 feet wide, and the feldspar occurs in crystals 1 inch to 1 foot long. The feldspar most common in Pennsylvania deposits is microcline. Quarrying has been done mostly between Marcus Hook, Delaware County and West Grove, Chester County, and especially near Avondale and Sylmar. In 1920 production was 8,562 tons valued at $81,104. In 1925 the production was 1,330 tons valued at $4,722. but in 1930 had nearly ceased.

Fig. 115. Feldspar vein at Elam, Delaware County. Photo by R. W. Stone.

Mica.

Mica is widespread as minute flakes scattered through rocks, or in some rocks, as mica schists, it is a principal constituent. Commercial mica comes from veins of coarsely crystalline granite or pegmatite. Many large blocks of mica have been found in such veins in southeastern Pennsylvania, but not in sufficient quantity or of good enough quality.

Quartz or Silica.

Quartz is the most common mineral found in nature. It occurs in crystals and other forms. Pure crystals find many uses, as for "fused quartz ware" for chemical use, for optical purposes, etc. Quartz crystals have been so abundant in some localities that they have been gathered by farmers in commercial quantity, especially near York. Vein quartz is found in many counties and has been quarried on a small scale in places in southeastern Pennsylvania for use in pottery, false teeth, and abrasives. Certain so-called white clays prove on analysis to be nearly pure quartz in a very finely divided state, in which form it can be separated and cleaned and sold as silica for use as a polishing powder, filler for paper, fertilizers, etc.

Glass sand produced abundantly in Pennsylvania is composed of quartz grains and is nearly pure silica.

Silica may also occur as tripoli or diatomaceous earth, or it may be prepared by air separation of fines of crushed quartzite. Pennsylvania is producing silica but production figures are not available.

Miscellaneous Minerals.

Many other minerals are found in Pennsylvania, most of them serving as cabinet specimens for mineral collections, though some of them are of gem quality. Among these may be mentioned:

Beryl, a pale blue, green, and yellow silicate of alumina—a gem when pure. Fine specimens, some of gem quality, have been found at many places in Chester, Delaware, and Philadelphia counties.

Fluorite, a calcium fluoride, occurs in single crystals in many of the southeastern counties of the State.

Garnet. A group of related minerals of brilliant colors, especially red, often used as gems. Garnets are abundant in gneisses and granites of the southeastern counties. Fine specimens have been found in the quarries of Delaware County.

Greenockite, a sulphide of cadmium occurs as orange-yellow incrustations on zinc ores at Friedensville, Lehigh County. Cadmium was obtained in secondary recovery from the zinc mines of Lehigh County.

Celestite, a sulphate of strontium, a pale blue mineral used in refining sugar and in medicine, has been noted at Bells Mills, Blair County, in bands less than an inch thick in shaly limestone.

Rutile, which contains titanium, has been found near Parkesburg, Chester County, and at other places in Chester and Delaware counties.

Strontianite, the carbonate of strontium, is reported as found near Mt. Union, in Mifflin County.

Tourmaline, a gem stone when clear, occurs as long black crystals in pegmatite and some quartz schist in the southeastern part of the State. Much fractured black crystals are common in the Fazio feldspar quarry at Embreeville, Chester County.

Zircon, a silicate of zirconium, has been found in the South Mountain of Berks County and at a number of places in western Pennsylvania, but not in commercial quantity.

Underground Water.

The Pennsylvania Geological Survey in cooperation with the United States Geological Survey has initiated a study of the underground waters of the State. Results are not ready for publication. The United States Geological Survey Mineral Resources report for 1913 lists 41 mineral springs. The production that year was 2,163,931 gallons valued at $190,459. These springs are confined mostly to the western tier of counties and the southeastern counties, with a few scattered wells and springs elsewhere. Production statistics have not been collected in recent years.

POWER.

Power may be classed as a secondary product of the mineral industry in a general group of secondary industries which include clay products, cement, lime, coke and its by-products, and the metallurgy of iron and other ores. The following figures are mostly from the United States Geological Survey Water Supply Paper 579. These figures were obtained by a census of manufactures, mines and quarries, agriculture, irrigation and drainage, electric central stations, electric railroads, steam railroads, ships, automobiles, and work animals not on farms. They show horsepower equipment, not horsepower produced—that is, they show capacity, not use.

Installed used horsepower in Pennsylvania.

Agriculture			920,000
Electric central stations			2,560,000
Electric railways			255,000
Manufacturers	5,107,000		
purchased	1,578,000	leaving net	3,529,000
Mining (1919)[1]	1,999,000		
purchased	360,000	leaving net	1,639,000
Steam railways[2]			3,357,000
Total			12,260,000[3]

[1] Figures for 1919 used as amount of purchased power in mining not available for 1923.
[2] Obtained by multiplying the mileage of railroads in the State by a factor obtained by dividing the horsepower of steam railways in the United States by the miles of track in the United States; from U. S. Geological Survey Water Supply Paper 579, p. 73.
[3] Does not include automobiles or ships. Exceeds the power of any other State on these items.

The corresponding figures for New York gave a total of 9,253,000 horsepower. According to these figures Pennsylvania leads in the production of power.

The Pennsylvania Giant Power Commission made the following analysis in its report in 1925: (page 59)

Power used in Pennsylvania.

	Kilowatt hours
Steam railways	3,500,000,000
Iron and steel industries	6,763,000,000
Mining	2,000,000,000
Industrial power	3,700,000,000
Commercial light and power	660,000,000
Domestic service	257,000,000
Municipal service	120,000,000
Electric railways	900,000,000
Total	17,900,000,000

Of this 520,000,000 kilowatt hours came from prime movers other than steam.

CONSERVATION AND MINERAL RESERVES OF PENNSYLVANIA.

Inquiry is often made as to the reserves of the several minerals found in Pennsylvania. For some minerals the necessary data are fairly accurate and available. For most of them, however, only the barest guesses can be made. It is not possible to assign any value to these reserves as value depends so largely on transportation facilities and every change in those facilities changes all values in the district affected. The resources will be taken up in order as in the preceding pages.

Coal. For detailed figures see Bituminous Coal Resources of Pennsylvania, by Reese and Sisler; Anthracite Mining Loses, by James D. Sisler; Anthracite Culm and Silt, by Sisler, Fraser and Ashmead. The summary figures by counties were given on a preceding page. The totals may be repeated here.

Bituminous coal reserves, in short tons.

Original deposits	75,093,459,000
Mined out and lost	5,823,163,000
Still in ground	69,270,296,000
Estimated mining loss	25,247,456,000
Recoverable reserves	44,022,840,000

Anthracite reserves, in long tons.

Coal remaining in ground	16,354,676,000
Estimated unrecoverable and lost	7,375,202,000
Estimated recoverable coal	8,979,474,000

Conservation of coal. Wastage of coal occurs in mining and in use. Recent studies have shown that in the bituminous fields of Pennsylvania mining losses total 28.6 per cent, of which 15.5 per cent is estimated to be avoidable. Losses differ in different fields, being only 18 per cent in the Pittsburgh coking field, of which 9 per cent is thought to be avoidable. In the anthracite fields present recovery for all fields is estimated at 61.1 per cent with a total loss of 38.9 per cent of which 4.3 per cent is in preparation. This should be compared with estimated recoveries in 1880 of from 27 to 39 per cent. In 1902 recovery was estimated at 50 per cent.

The greatest waste of coal is in its use, but rapid advances have been made recently in reducing this waste. The following table illustrates how losses may occur in producing electric power.

	Per cent
Loss in boiler	40
Evaporating water in coal 4%; waste gas from combustion, 10%; heating surplus air, 10%; incomplete combustion, 2%; coal in ashes, 5%; radiation, 9%.	
Loss in engine and transmission	55
In steam piping 1.2%; in feed-water heater, 7%; exhaust, 46.5%; between engine and switch, 0.3%.	
Energy at switch board, actually used	5
Total energy in coal	100

Good practice today is cutting boiler losses to 25 per cent or less; some recent installations report losses under 15 per cent.

Pounds of coal required in modern plants.

	1919-20	1927
Public utilities per kwh.	3.2	1.83
Railroads per 1,000 ton mile	197	148

Formerly all coke was made in beehive ovens; recovery 65 per cent. By-product ovens today recover 70.4 per cent plus value of by-products.

It is claimed that coal converted into gas and used in internal combustion engines will realize 25 per cent or more of the energy of the coal. The use of mercury vapor in place of water in the boiler for one stage is claimed to double the efficiency of present engines. Efficiency is growing in other uses of coal.

Oil. Pennsylvania's oil resources go into large figures.

	Barrels
Estimated total original oil in ground	2,138,000,000
Recovered 1859-1930 inclusive	841,411,000
Present rate of annual recovery (1930)	12,797,000
Estimated future recovery by drilling (G. H. A.)	600,000,000
Estimated oil left in rock	700,000,000

The above estimates differ notably from the figures previously quoted from the American Petroleum Institute. They are based on a study of production curves which indicated 970,000,000 barrels as the total oil in Pennsylvania obtainable without secondary recovery methods. Ex-

perience in the Bradford field indicates a secondary recovery of more than the initial recovery. Assuming for the State an average secondary recovery of 50 per cent of initial recovery and adding oil still to be obtained on initial recovery gives the figure cited. The estimate of oil left in the ground is a pure guess based on tests of the Bradford sand after secondary recovery, which indicates that 65 per cent of the original content of oil is still in the rock. The figure given is one-half that or 32.5 per cent of the whole.

Conservation of oil. Oil today has so high a value that little of it is wasted. There has been considerable waste in the past. Today the larger companies in particular are using the best methods they can devise to get the oil with least cost, to prevent loss while in storage or transit, and to make the best possible use of it. Boundary line drilling and other wasteful methods much followed in the west, possibly because of the abundance of oil there, are not prevalent in Pennsylvania.

Natural gas. Natural gas is clearly an exhaustible resource. In the early days of the oil and gas industry vast quantities of gas were wasted, through open flow from wells, as flambeau, in leakage from pipe lines and finally through inefficient use. It would probably be safe to say that up to 1900 over 90 per cent of the natural gas obtained in Pennsylvania was wasted, and that between 1900 and 1920 over 80 per cent of the gas obtained was wasted. Quite aside from losses in the field and in transportation, were losses in use. Some of these have been estimated as follows: in coal furnace 75 per cent; in ordinary gas furnace 65 per cent; in good gas furnace 25 per cent; in cook stove, (4 oz. pressure) 87 per cent, (at 0.2 oz. pressure) 63 per cent. Since 1920 there has been great improvement in the efficient use of gas as well as reduction in field losses.

The curve of production of natural gas in Pennsylvania is too irregular and has been maintained at too high a level to form any basis for an estimate of the reserves. That would require an acreage study such as is not now available. For several years production has exceeded 100,000,000 M. a year. A most optimistic estimate would give one hundred years as the life of the field allowing an average decline of 1,000,000 M. a year.

Clay and shale. The clays of the bituminous coal fields underlie the coal beds and may safely be estimated as twice as thick as the coal beds. In addition much coal below workable thickness is underlain by a workable thickness of clay. This would yield an estimated total (average 20 feet thick, over 10,000 square miles) of 400 billion tons. Of the shales making up much of the coal measures there should be at least one trillion tons available. Of shales outside the coal measures the amount is almost incalculable. This includes all clays and shales. Only a small fraction of this is high grade clay and shale. If they make up only one-tenth of the whole, the quantity is still formidable. The amount of flint clay cannot be estimated but is small, for flint clay, as a rule, is confined to surface outcrop.

Sand and sandstone. Limitless for all practical purposes. High grade stone is limited but abundant. For example, the Oriskany sandstone outcrops for many hundred miles in Pennsylvania. Probably every mile of its outcrop contains on the average over 100,000,000 tons

of sandstone above drainage. One hundred miles of the outcrop of this single bed would supply all the needs of Pennsylvania at the present rate for 600 years or more, without going below drainage. This bed is only 200 feet thick, out of an estimated total of 7,000 feet of sandstone in the State. It is clear therefore, that quantity of sandstone is not a problem. The problem is to find enough sandstone of just exactly the character and quality desired. Aside from high grade building stone, comparable with the famous stone from the quarries near Cleveland, Ohio, of which some is known near Waynesburg, Greene County, there appears to be an abundance of sandstone of all kinds, fairly well spread over the State. Sand and gravel are abundant for immediate needs, but present supplies are definitely limited, unless we include ground sandstone. It may be doubted if present supplies of natural sand will outlast the present century.

Limestone. Limestone, like sandstone, exists in endless abundance, though high calcium limestone is not as widely distributed as high silica sandstone.

Granite, gneiss and schist. Schist and gneiss are abundant in southeastern Pennsylvania, and have long been used for structural purposes. Recent studies indicate that there is probably a limitless quantity of these, though possibly only a limited quantity of high grade stone. Granite is of very limited occurence and quantity, and confined to southeastern Pennsylvania. Prospecting might disclose sufficient to serve a considerable demand for a long period.

Trap, diabase and rhyolite. Form considerable hills in southeastern Pennsylvania. Enough to serve all needs for many thousand years. Special varieties more limited.

Serpentine. In southeastern Pennsylvania. That suitable for building stone is not abundant, but sufficient to supply present demand indefinitely.

Talc. Very little high grade rock known in State though considerable bodies of mixed rock are known.

Slate. Slate occurs in a well-defined belt in southeastern Pennsylvania and of almost limitless quantity. High grade slate however, appears to be confined to rather narrow belts of limited extent. The slate in proven territory would probably be only a small multiple of the quantity already taken out. It is possible that future prospecting will reveal endless quantities. The area within which slate may be found is very large. The area of present workings is a small fraction of one per cent of the whole slate area.

Iron. Estimates of the iron ores of the United States by C. W Hayes, made in 1909, gave Pennsylvania:

	Available, tons	*Not available, tons*
Clinton ore (red fossil ore)	5,000,000	.....
Brown ores (limonites) (Pa., Md., & N. J.)	10,000,000	12,000,000
Carbonate ores	.....	46,000,000
Magnetite ores	15,000,000	35,000,000

It appears now that all of the magnetite ore may be transferred to the available column, and some of the carbonate ore must needs be

transferred to the available column to take care of the yearly production of that ore, especially for paint. Making such transfers gives a possible reserve of available iron ore of 75,000,000 tons. Future prospecting may greatly increase this figure.

Copper. Copper will doubtless continue to be recovered as a secondary product in mining magnetite. Copper minerals are widely scattered in certain rocks, but it is uncertain whether any of these deposits may be considered workable. Further discoveries or improved methods of recovery, combined with higher prices, may lead to future independent recovery. The total quantity appears, however, to be very small.

Pyrite. Large quantities of pyrite occur in or with the beds of coal, and are available whenever the demand warrants their recovery. The total is probably many million tons. Not of present value.

Lead and zinc. Small commercial quantities of both lead and zinc are believed to be left in the ground. Total production, if any, very small.

Aluminum. Aside from the aluminum locked up in common clays and the silicate minerals, an unknown quantity of aluminum may in the future be obtained from certain high-alumina clays found with normal flint clay of west Pennsylvania. Quantity unknown.

Manganese. No commercial deposits known. No large deposits likely to be found.

Chromium. Probably unmined commercial deposits. Possibly of relatively large size.

Nickel. Reported that ore in Gap mine was not exhausted when the mine closed. No other possible commercial deposit known.

Mineral paint ores. Carbonate iron ore abundant. Ochers and other pigments in large quantities, but said to be of inferior quality.

Salt. Endless quantity in beds at great depth. Probably large quantity still available in brines from sandstones.

Graphite. Probably considerable quantities of low grade.

Asbestos. Probably small deposits. Little value.

Magnesia. Endless quantities of magnesia obtainable from dolomites. No other commercial source.

Barite. No large deposits known. May be small production from scattered bodies.

Feldspar. Small deposits, should lead to small production for many years.

APPENDIX A.

Hunting for Minerals.

Over most of the State few distinct minerals are to be found. Quartz in one form or another is common. Aside from it, pyrite, "fool's gold," is probably the most widespread mineral, and several iron ores, which are minerals when pure, are fairly abundant. But in general the greatest variety of mineral specimens is found in the southeastern corner of the State. In the museum of the Philadelphia Academy of Science a whole gallery is given up to a display of minerals collected in this State.

Several minerals have been found in most, if not all, of the quarries in Chester, Delaware, and Philadelphia counties. It is therefore not necessary to list these quarries. Anyone living within those counties will have no difficulty in finding quarries, though it may not be easy to find minerals in them. Mineral collections of value are the result of repeated search covering several years. It may, however, be well to give the names of places in some of the other counties where several kinds of minerals have been found:

Adams County, in South Mountain west of Gettysburg.
Berks County: Jones Iron Mine near Morgantown.
Bucks County: New Britain Twp., New Hope, Feasterville.
Lancaster County: Gap mine. Chrome mines in southern part of the county. Pequea mines, Rock Spring.
Lebanon County: Cornwall.
Lehigh County: Chestnut Hill, Friedensville, Ironton, Siesholtzville.
Montgomery County: Shannonville, Edge Hill, Lafayette.
Northampton County: Easton, Hellertown.

This takes no account of the great number of places in which one, two or three minerals have been reported. On the other hand the places mentioned have long been known and therefore thoroughly searched and many of the mines are now abandoned or fallen shut. Still there is always the possibility that some things have been overlooked and these places might well repay a careful search by those living in their neighborhood.

Fossils.

Although fossils are not so abundant in Pennsylvania as in some other States, they can be found if one knows where to go and will look closely enough. In the southeastern part of the State fossils are nearly "as scarce as hens' teeth." Within the coal fields plants are likely to be found in the waste material brought out from the mines; most of the limestones of the Coal Measures contain shells. Some of the thinner limestones will yield fossils nearly everywhere, if carefully examined.

No list of good fossil localities in the State has ever been published nor is such a list available. The volumes of the Second Geological Survey, to be found in the libraries of all the larger towns, in partic-

ular volumes O, O2, O3, P, P2, P3, and P4 contain reference to localities where fossils have been found. Many of the other reports in describing local sections of the rocks make note of fossils found in them; so that, if no particular reference to fossils is found in the volumes listed, it would be well to search through the volume describing your particular county. Those who can find an abundance of good fossils in their neighborhood would do well to let others know of it, probably through the State School Journal. Exchange material, whether fossils, rocks, or minerals, should always be first class.

To list all of the localities where fossils have been reported as found in Pennsylvania would fill a small book. Possibly a few localities taken at random of places from which members of the Second Survey obtained more than the usual number of fossils may be helpful.

Mifflin County: Reedsville, just above mill dam, upper end of Jacks Mt. gap; McKeesville, at McKees ore banks, 1 mi. northwest; Matilda Furnace.

Centre County: Bellefonte, one-fourth mile W. of; N. side of creek.

Huntingdon County: Tyrone Forge, Little Juniata River "below covered bridge;" Orbisonia, above ore bed; Barre Twp., A. B. Miller farm, Warriors Ridge; near Rough and Ready.

Bedford County: Henrietta furnace, south side of Morrison's Cove.

Blair County: Bells Mills, 2 miles southwest of; Tyrone, quarry north of city.

Carbon County: Hazardville, Mansing quarry.

Monroe County: Marshalls Cr., 1 mile southwest of Marshalls Falls; Stroudsburg, ½ mile north of.

Pike County: Dingmans Falls; Bushkill, Wallpack, bed of river.

Tioga County: Lawrenceville; Mansfield, 1 mile north of town.

Bradford County: Franklindale, 1 mile east of town; north and west of Leroy.

Erie County: Many of the beds back from Lake Erie are very fossiliferous.

McKean County: Big Shanty, near station.

Lycoming County: West line of Anthony twp, W. Marshall farm; Linden, from iron ore bed.

Westmoreland County: Congruity, ½ mile north of; Harveys 5 Points.

Greene County: ½ mile from Carmichaels, roof shale of Waynesburg coal; 2½ miles from Jollytown.

Perry County: Center twp., north end of Dowans Narrows; Brickfield, 1 mile southwest of New Bloomfield; ½ mile north of King's Mill, Penn Twp.; near Drumgold's tannery, Shermans Creek, Carroll township; New Bloomfield, ½ mile S. of, on Carlisle road; New Bloomfield, 2½ miles northwest of, at Clarks Mill; New Bloomfield, at W. Bennett's mill.

Columbia County: Bloomsburg, railroad cuts east of asylum.

Snyder County: Railroad cut 1 mile south of Selinsgrove.

Beaver County; Cannelton, cannel coal mines.

The above list taken from the reports of the Second Geological Survey mentions only places where an unusually large number of species have been gotten. Thus at Cannelton mines, Beaver County, 242 different kinds of plants have been found. At Campbell Ledge near Pittston, Lackawanna County, 101 different kinds were collected.

In general the above list does not include locations at mines in both bituminous and anthracite fields from which collections can be made. Nor does it list localities where fossils have been found in the thin limestones of the coal fields. The list given might be multiplied a dozen times from the counties west and north of Kittatinny or North Mountain. Once interested in the subject a boy or girl may get all the thrill of an old time gold prospector in searching all of the rock outcrops in the neighborhood for fossils.

The identification of the fossils is a much more difficult matter, though there is possibly no better training in accuracy of observation than that obtained in identifying and naming fossils. For this purpose students should consult the reports of the Second Geological Survey already listed. Unfortunately the fossils in the "Dictionary of fossils of Pennsylvania," P4, volumes 1 to 3, are listed alphabetically by genera which makes it difficult to find a species of which not even the generic name is known.

APPENDIX B.

PUBLICATIONS OF THE PRESENT GEOLOGICAL SURVEY

All available printed bulletins can be secured through the Commonwealth of Pennsylvania, Division of Documents. Checks for publications upon which price has been set must be made out to the Commonwealth of Pennsylvania.

Those marked z are not available from official sources.

Miscellaneous Papers

1.z The Story of the Survey, by George H. Ashley. An illustrated brochure of 20 pages, containing the history of official geologic work in Pennsylvania and the reasons for the present Survey and its proposed methods of work.

2.z The Work of the Survey, by George H. Ashley. A brochure of 18 pages, 2 figures, describing the organization and operation of the Survey.

Bulletins*

M1.z The Oil and Gas Fields of Pennsylvania, Vol. 1, Introduction, by George H. Ashley and J. French Robinson, 1922, 79 pp., 4 pls., 9 figs., 1 color map. A condensed, introductory description of the origin, mode of occurrence, and conditions of development of oil and gas, with a brief description of each of the oil and gas fields of the State; also a small scale reconnaissance map of the oil and gas fields.

M2.z Oil Resources in Coals and Carbonaceous Shales of Pennsylvania, by Chas. R. Fettke. 1923. 119 pp., 6 pls., 16 figs. Describes the petroleum situation, explaining methods of distilling coal and shale, and gives results of tests on 122 samples of coal and shale.

M3.z The Silica Refractories of Pennsylvania, by E. S. Moore and T. G. Taylor. 1924. 100 pp., 16 pls., 10 figs. Describes the character, distribution, and quarrying of ganister and mica schist, and the properties, manufacture, and uses of silica brick.

M4.z Bituminous Coal Losses and Mining Methods in Pennsylvania, by James D. Sisler. 1924. 216 pp., 1 pl., 29 figs. Describes the distribution, thickness, character, and reserves of bituminous coal by districts, and indicates the sources of loss and waste at the mines.

M5.z Lead and Zinc Ores of Pennsylvania, by B. L. Miller. 1924. 91 pp., 5 pls., 7 figs. A description of the distribution, geologic occurrence, and origin of the ores, and a history of mining operations.

M6. Bituminous Coal Fields of Pennsylvania.

Part I. General description of coal. 50c.

II.z Detailed description of coal fields, by J. D. Sisler. 1926. 511 pp., 14 pls., inclu. 6 color maps, 152 figs. A report giving details of the bituminous coal beds. The description is by counties.

III. Bituminous Coal Resources. 25c.

IV. Analyses of Bituminous Coal. 1925. 268 pp., 1 pl. This report by the U. S. Bureau of Mines gives several hundred measurements and analyses of bituminous coal mined in Pennsylvania. 25c

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* The letters used with publication numbers tell the series, as follows:

A. Atlas, topographic and geologic. The numbers refer to quadrangles counting from west to east and north to south, each north-south tier running from 1 to 9.
C. County reports.
G. Geology, general .
M. Mineral Resources.
S. Soil reports.
W. Water resources.

M7.z Limestones of Pennsylvania, by B. L. Miller. 1925. 368 pp., 15 pls., inclu. 1 color map, 7 figs. Describes the character, origin, and uses of limestone and the geographic and geologic distribution of the principal deposits. The description of the limestone of each geologic age is arranged by counties.

M8.z Anthracite Losses and Reserves in Pennsylvania, by Dever C. Ashmead. 1926. 71 pp., 1 pl., 13 figs. This report gives the thickness and acreage of each bed in the anthracite field, the percentage of coal recovered in mining, explains how and why some anthracite is lost, and gives an estimate of the quantity of anthracite remaining in each bed, and in each of the four fields.

M9.z Slate Deposits of Northampton County, by C. H. Behre, Jr. 312 pp., 36 plates, 49 figures, 2 color maps. Describes the slate quarries in the Bangor, Wind Gap, Portland, Belfast, Chapman, Seemsville, Point Phillip, and Slatefield districts, with special reference to the geologic structure.

M10.* Fire Clays of Pennsylvania, by J. B. Shaw, 69 pp., 9 figures (available on request).

M11.* Molding Sands of Pennsylvania, by R. W. Stone and American Foundryman's Association. 94 pp., 21 pls., 10 figs. (available on request).

M12. Anthracite culm and silt, by James D. Sisler, Thomas Frazer and Dever C. Ashmead. 1928. 259 pp., 34 pls., 21 figs.

M13.* Feldspar in Pennsylvania, by R. W. Stone and H. Herbert Hughes. 60 pp., 20 pls., 6 figs. (available on request).

M14. Magnetite Deposits of French Creek, Pennsylvania, by Laurence L. Smith. 1931. 52 pp., 5 pls., 5 figs. Describes the French Creek magnetite mine at Saint Peters, Chester County.

County Reports

C1. Adams County Report.

Part 1. Geography and geology, by George W. Stose. (Submitted for printing).

II.z Mineral Resources, by George W. Stose, 1925. 64 pp., 11 pls. inclu. 1 color map, 1 fig.

III.z Soil Survey, by A. L. Patrick and H. H. Bennett. 1924. 44 pp., 1 color map.

C2. Geology and mineral resources of Greene County, Pennsylvania, by R. W. Stone. (Submitted for printing).

Geological Reports.

G 3.* Pennsylvania Caves, by R. W. Stone. 1930. 63 pp., 34 figs., (available on request).

Topographic and Geologic Atlas of Pennsylvania

Each atlas contains a topographic map, one or more geologic maps, and text describing the geology and mineral resources.

A37.z Greensburg Quadrangle, by Meredith E. Johnson. 1926. 162 pp., 13 pls., 25 figs. inclu. 10 color maps.

A65.z Punxsutawney Quadrangle, by George H. Ashley. 1926. 145 pp., 6 pls., inclu. 5 color maps, 26 figs.

A178.z New Holland Quadrangle, by Anna I. Jonas and George W. Stose. 1926. 40 pp., 7 pls., inclu. 2 color maps.

A206.z Allentown Quadrangle, B. L. Miller. 1926. 195 pp., 15 pls., inclu. 2 color maps, 2 figs.

A5.* New Castle Quadrangle, by F. W. DeWolf. 1929. 238 pp., 18 pls. (5 colored), 17 figs. $1.00.

A27.* Pittsburgh Quadrangle, by Meredith E. Johnson. 1929. 236 pp., 33 pls. (10 colored), 28 figs., $1.00.

A168.* Lancaster Quadrangle, by Anna R. Jonas and George W. Stose. 1930. 106 pp., 23 pls., (2 colored), 10 figs. $1.00.

In addition to the printed bulletins, the Survey has issued a number of mimeographed bulletins; most of these are covered by later printed reports. A few of them have not been so covered, and are listed here.

* A fire in the Division of Distribution, Bureau of Publications in May 1927, destroyed the books here marked z; those marked * were published since the fire. All these books can be consulted in most of the Public Libraries of the State. This does not apply to M6, Part II, and Adams County Reports, Parts II and III, which had not been distributed to libraries at the time of the fire.

Bulletins (Mimeograph)

Missing numbers represent bulletins which have been discontinued because the subject is covered by printed bulletins issued later.

1. Effect of the War on the Price of Coal in Pennsylvania—by G. H. Ashley—3 pages.
7. A High-grade Building Stone in Greene County, by G. H. Ashley, 2 pages.
14. Future Sources of Power—by G. H. Ashley—3 pages.
15. Mineral Resources of Pennsylvania—by G. H. Ashley—12 pages.
20. Pennsylvania Iron Ores—by J. Ross Corbin—3 pages.
28. Magnesite in Pennsylvania—by R. W. Stone—3 pages.
40. White Clay Deposits at Saylorsburg, Monroe County, Pa.—by Frederick B. Peck—7 pages, 1 map.
45. White Clay Deposits in Central Pennsylvania—by E. S. Moore—6 pages, 1 map.
47. Manganese Occurrences in Eastern Pennsylvania—by Benjamin L. Miller—11 pages.
48. Pyrite from Bituminous Coal Mines in Pennsylvania—by Henry Leighton—19 pages, 3 plates, 1 map.
51. New Oil Pool at Tidioute and Gas Pools near Corry and Meadville, Pa.—by M. E. Johnson—4 pages, 1 map.
56. Oil Fields Rejuvenated—by Robert B. Bossler—14 pages.
58. Potash Fiasco in Tioga County, Pa.—by R. W. Stone; and, Simple Tests for Potash by W. B. Hicks—7 pages.
59. Bog Iron Ore—by J. Ross Corbin—5 pages.
61. Magnetite in Pennsylvania—by J. R. Corbin—6 pp., 1 map, 1 chart.
63. Brown Iron Ores in Pennsylvania—by J. Ross Corbin—7 pages, 1 map, 2 charts.
66. Oil and Gas Development in Pennsylvania in 1922—by M. E. Johnson—4 pages.
72. Flagstone Industry in Northeastern Pennsylvania—by R. W. Stone—7 pages.
75. Rocks of the Quarryville Quadrangle, Pa.—by Anna L. Jonas—9 pages, 1 map.
76. Calcareous marl in Pennsylvania south of the Terminal Moraine—by J. B. R. Dickey—10 pages, 3 figs.
78. Gas in Leidy Township, Clinton County, Pa.—by Meredith E. Johnson—7 pages, 1 map.
79. Tidioute Oil Pool, Warren County, Pa.—by Meredith E. Johnson—17 pages, 3 maps.
82. Roofing Granules Industry in Southeastern Pennsylvania—by R. W. Stone—4 pages.
83. The Living Earth—by G. H. Ashley—4 pages.
86. The Age and Origin of the Earth—by G. H. Ashley.
88. Silurian Stratigraphy at Lehigh Gap, Pennsylvania—by G. H. Ashley—6 pages.
89. A Practical Classification of Coals—by Geo. H. Ashley—16 pages.
90. Pennsylvania, the Makings of a World Power—by Geo. H. Ashley—23 pages.
91. A Stratigraphic Time Scale—by Geo. H. Ashley—10 pp. 1927.
93. The Canadian System (Technical Bulletin)—by Geo. H. Ashley—10 pages, 1928.
94. High Spots in Pennsylvania—Geo. H. Ashley—8 pp., 1928.
95. Mineral Resources of the Lower Allegheny-Beaver River District—by Geo. H. Ashley—6 pages, 1928.
96. Sand and Gravel in the Scranton Region, Pennsylvania,—by Prof. Freeman Ward, 15 pp., 1928.

97. Mineral Resources of Pennsylvania, by Geo. H. Ashley—9 pages, 1928.

99. Sand and Gravel in the Reading Region, Pennsylvania, by Prof. Freeman Ward—13 pages, 1929.

100. Sand and Gravel in the Altoona Region, Pennsylvania, by Prof. Freeman Ward—15 pages, 1930.

101. The Topographic and Geologic Survey, a brief summary of its work since 1919, by George H. Ashley—6 pages, 1930.

102. Gas in the Tioga Region, Pennsylvania, by S. H. Cathcart and Bradford Willard—21 pages, 1 map, 1931.

103. River Coals of Eastern Pennsylvania, by John M. Hills, 33 pages, 1931.

Publications of the Topographic and Geologic Survey Commission.

The following is a list of the publications issued by the Topographic and Geologic Survey Commission, sometimes called the Third Geological Survey. None of these are available, but can be consulted in some of the larger libraries.

General Reports

Report of 1899 and 1900. Results of topographic mapping and cooperative geologic work. 135 pp.

Report of 1899-1906. Progress report. Triangulation, primary traverse and elevation data. 308 pp.

Report of 1906-1908. Progress report. Engineering data. Geology of Southwestern Pennsylvania, by George H. Ashley, R. W. Stone, Chas. Butts, and M. J. Munn. 375 pp., 21 pls., 21 figs.

Report of 1908-1910. Engineering data. Natural gas development in Pennsylvania, by F. G. Clapp. Fauna of the Allegheny and Conemaugh series in Western Pennsylvania, by Percy E. Raymond. 103 pp., 6 pls., 4 figs.

Report of 1910-1912. General report. The York Valley limestone belt in York County, by M. L. Jandorf. Geological origin of the freshwater fauna of Pennsylvania, by A. E. Ortmann. Peridotite dike in Fayette and Greene counties, by L. B. Smith. Mineral production. 178 pp., 21 pls., 23 figs.

Report of 1912-1914. Progress report. Copper developments in South Mountain Region, by G. M. Bevier. Mineral production in 1912. 232 pp., 5 pls.

Economic Reports

Report No. 1. Geology of the Oil and Gas Fields in Sewickley Quadrangle, by M. J. Munn. 1910. 170 pp., 10 pls.

Report No. 2. Geologic Map of Southwestern Pennsylvania. 1914. 29 pp., 10 pls.

Report No. 3. Geology of the Oil and Gas Fields of the Clarion Quadrangle, by M. J. Munn. 1910. 112 pp., 9 pls., 1 fig.

Report No. 4. The Mineral Pigments of Pennsylvania, by Benjamin L. Miller. 1911. 102 pp., 29 pls., 9 figs.

Report No. 5. The Talc and Serpentines of Eastern Pennsylvania, and The Cement Industry of Lehigh and Northampton Counties, by Frederick B. Peck. 66 pp., 17 pls., 9 figs.

Report No. 6. Graphite Deposits of Pennsylvania, by Benjamin L. Miller. 1912. 148 pp., 17 pls., 1 colored map.

Report No. 7. Engineering Data., by Richard R. Hice, 1913. 450 pp., 3 pls.

Report No. 8. The Mineral Production of Pennsylvania. 1911. 84 pp.

Report No. 9. Minerals of Pennsylvania, by Amos P. Brown and Frederick Ehrenfeld. 1913. 160 pp., 10 pls., 1 fig.

Report No. 10. The Broad-Top Coal Field, by James H. Gardner. 1913. 82 pp., 32 pls., 1 fig.

Report No. 11. The Mineral Production of Pennsylvania. 1913. 107 pp.

Report No. 12. Glass Manufacture and the Glass Sand Industry, by Charles Reinhard Fettke. 1919. 278 pp., 108 pls.

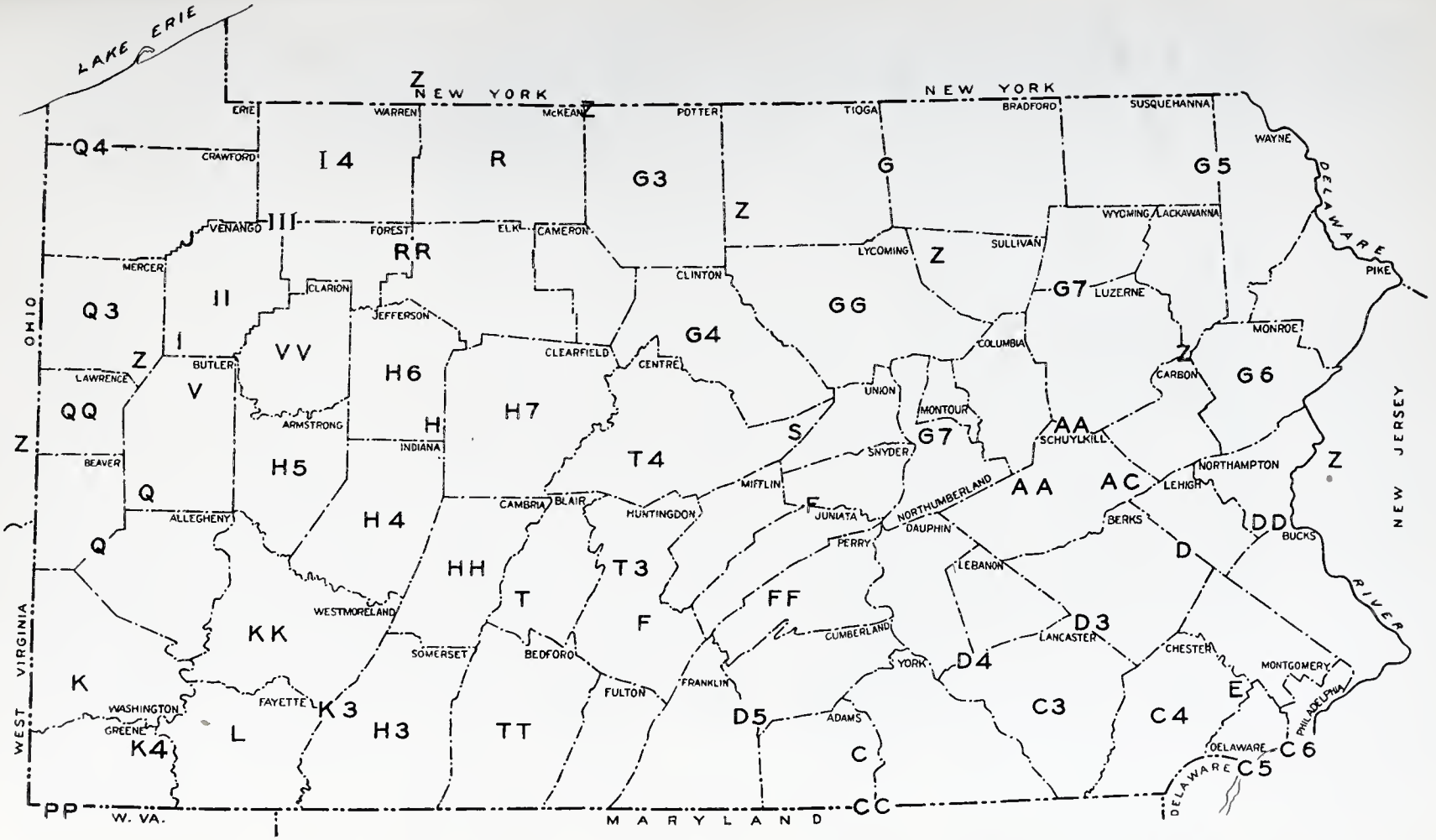

Fig. 116. Map showing areas covered by Second Geological Survey of Pennsylvania Reports.

So much of Pennsylvania has not been studied geologically since the time of the Second Geological Survey, that reports of that Survey still have large value, and for many areas are the only available source of information. The reports, about 120 volumes, are of several kinds.

1. Annual reports covering the years 1885 to 1887 inclusive.
2. A series of miscellaneous reports on Minerals of Pennsylvania, Chemical Analyses, Catalogues of Specimens, Coal Flora, Hand Atlas, and the Terminal Moraine.
3. A summary report issued between 1892 and 1895, which describes briefly all of the findings of the Survey.
4. A series of atlases of the anthracite field published on the scale of 800 feet equal 1 inch, showing the outcrops of all the coal beds, and indicating the mine workings on the coal beds, as they were at the time of the Survey. These are accompained by texts vols. AA and AC.
5. A series of county reports on the bituminous coal fields and surrounding areas. These reports are under the letters H to H7, I to I5, J, K to K4, L, Q to Q4, R to R2, V to V2.
6. The reports on petroleum and gas, under the letters I and J.
7. A series of reports on northeastern and middle Pennsylvania, under letters D, F, G, and T.
8. A series of reports on southeastern Pennsylvania under the letters C and E.

A subject reference to these reports follows:

Adams County. Vols. C, C2, Atlases D5 and D6.

Allegheny County, Annual Report, 1886, Pt. 1, Vols. K2, Q, K, I4.

Analyses of minerals, Vols. B, B2.

Analyses of coals, Vols. M, M2, M3, T4.

Anthracite region, general map, AA Atlas, Southern coal field, Pt. 1. General map, Annual Report, 1886, Pt. 3.

Anthracite region, Vol. AA, Pt. 1, Pt. 2, Annual Report, 1885, Pt. 3, Annual report, 1886, Pt. 2; Part 3 and Atlas.

Anthracite region, summary final report Vol. III, Pt. 1.

Anthracite maps, Atlas AA, Northern coal field, Parts 1 to 6; Eastern Middle, Parts 1 to 3 ; Western Middle, Parts 1 to 3; Southern, Parts 1 to 6.

Anthracite, methods of mining and appliances, Vol. AC and Atlas.

Armstrong County, with map, Vol H5.

Beaver County, Vols. Q and I4.

Bedford and Fulton counties, Vol. T2.

Berks County, Vol. D3, Part 2.

Bernice coal basin, Ann. Rep. 1885.

Bituminous coal field, Sum. Final Report, Vol. III, Part 2.

Blair County, coal measures, Vol. H2.

Blair County, Vols. F. T. and Atlas.

Blair County, Ann. Rep. 1885.

Blossburg coal field, Vol. G.

Bradford County, Vol. G.

Broad Top coal field Bedford, Fulton, and Huntingdon counties, Vols. T2 and T3.

Broad Top coal field, Final Sum. Rep. Vol. III, Part 2.

Bucks County, southern part, Vol. C6; central part, Vol. C7, Atlas.

Buried river valleys, Vol. Q2, p. xii, Ann. Rep. 1885.

Butler County, southern part, Vol. Q; northern part, Vol. V.

Butler County, oil region and wells, Vols. I3, I4, and V.

Cameron, Elk and Forest counties, Vol. RR and Atlas.

Cambria County, Atlas H2 and H3.

Centre County, Vol. T4.

Chester County, with map. Vol. C4.

Clarion County, Vols. V2, RR Atlas, I3, I4, J, I3 Atlas, V.

Clearfield and Jefferson counties, Vol. II.

Clearfield County, revised, Vol. H7.

Clinton County, Vols. G4, and I4.

Coal, formation, Vol. H, appendix.

Coal, classification of, Vol. M2.

Coal measures in Western Pennsylvania and Eastern Ohio, correlation of Vol. Q2.

Coke manufacture, special reports, G, L.

Columbia County, Vol. G7.

Cornwall ore mines, Ann. Rep. 1885.

Counties, summary geology of, Vol. X.

Crawford and Erie counties, Vols. Q4 and I4.

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Topographic Maps.

One of the major activities of the Topographic and Geologic Survey is cooperating with the U. S. Geological Survey in making a topographic map of the State. The actual work is done by the Topographic Branch of the Federal Survey, and the maps are to be obtained only from The Director, U. S. Geological Survey, Washington, D. C., for 10 cents each, or from stationers in the larger towns.

The maps are issued by quadrangles, each covering an area of about 17½ miles from north to south and 13½ miles from east to west, or an area 15′ of longitude and 15′ of latitude. They are published on the scale of 1:62,500, or nearly one inch equals one mile 1:63,360. They show the political boundaries, towns, roads, railroads, detached houses or buildings, and other works of man. These are printed in black. The streams and other water areas are printed in blue. The topography or shape and elevation of the land is shown by brown contour lines, or lines of equal elevation above mean sea level. Thus, the 1,200-foot contour on one of these maps has the same position as the shore line would be if the sea rose vertically 1,200 feet on the land. By this means it is possible to show not only the elevation of any point on the map, but also the slope or steepness of any hill, the gradient of rivers, roads, etc. The following sketch will help to give the relation between the actual topography and its representation by contours.

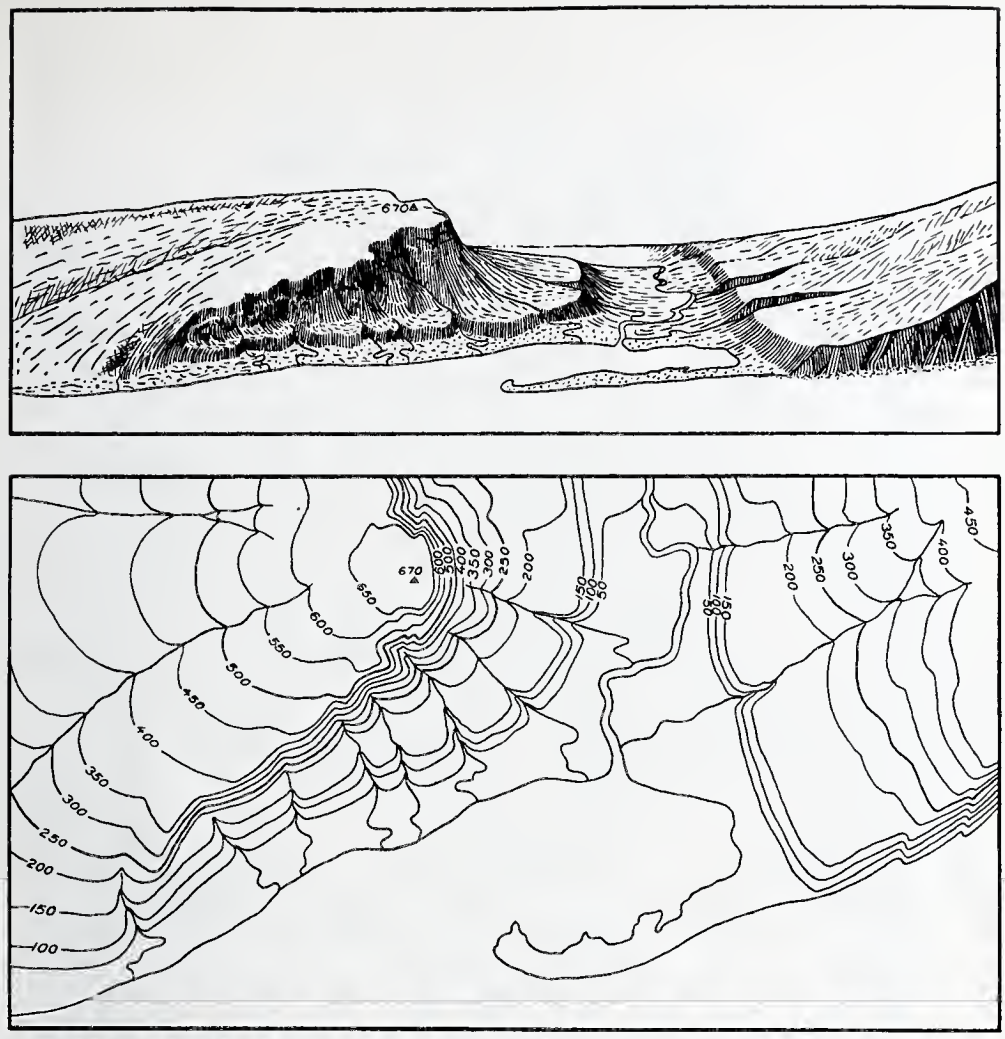

Fig. 117. Sketch showing how topography is represented by contour lines. (U. S. G. S.)

At the present time over 81 per cent of the State has been covered by topographic mapping. Not all of these maps have been engraved. The following diagram shows the progress of mapping, both topographic and geologic, and the names of quadrangles.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS
James F. Woodward, Secretary
TOPOGRAPHIC AND GEOLOGIC SURVEY
Geo. H. Ashley, State Geologist
Published by present Survey
LAKE ERIE
NEW YORK
NEW JERSEY
Under name. Topographic field work completed or in progress.
Under name. Engraved map available 10 cents each.
Over name, Geologic field work completed or in progress
A= Atlas by Pennsylvnia Geologic Survey
B= Bulletin by number. U.S. Geological Survey.
F= Folio by number. U.S. Geological Survey.
R= Reports by number, Pennsylvania Geologic Survey
*= Temporarily out of stock.
*= Stock exhausted, obtainable only from secondhand book dealers
INDEX TO TOPOGRAPHIC AND GEOLOGIC MAP OF PENNSYLVANIA

Fig. 118. Map showing areas covered by topographic and geologic mapping to date.